Final Master's Degree

ENGINEERING MASTER'S DEGREE IN ORGANIZATION

Organization improvement in Colas Mechanical Workshops

MASTER THESIS

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Abstract

Objective:

The aim of the proposed project is to optimize working conditions and processes into the mechanical workshops of Colas Midi-Méditerrannée, subsidiary of the world leader in road construction and maintenance, Colas.

Methodology:

The technique applied to reach the objective of the project, which origins come from the Japanese culture, is named “5S”. It is based on five fundamental pillars: Sort, Straighten, Shine, Standardize, and Sustain.

Results:

After an analysis of the initial workshop situation, the expected results consist in a change in the overall effectiveness of the workshop. If the methodology quoted is properly applied, this value should increase significantly.

Conclusion:

The sources that are causing a performance loss in the operations of the workshop are identified and eliminated. The effort involved in the project must be sustained in order to maintain the efficiency level achieved in a spirit of continuous improvement.

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Glossary

5S: It is a system which goal is to promote and sustain a high level of productivity in a workspace by applying five fundamental pillars on its organization. 5S not only helps companies to promote efficient working environments but establishes also a sustainable culture of safety.

Spans: Portion of vault or bridge in mechanical workshops where vehicles are parked during their maintenance.

Pit: Hole in the ground allowing mechanics to access vehicles from under. It is often located in the middle of a span.

Kanban: Kanban is the Japanese term for label. In the field of logistics, it designates a method of inventory management.

Boilermaking: An area dedicated especially for tasks dealing with metal but also cutting, welding or drilling operations.

Vehicle fleet: It designates all the vehicles available for work purposes.

Mechanic’s cart: It is a mobile cabinet with metal drawers to stock the smallest and high-frequency used tools. Thanks to its castors, it is possible to move it at ease.

Acronyms

CMM: Colas Midi-Méditerranée

MW: Mechanical Workshop

6SM: 6S Methodology

PPE: Personal Protective Equipment

QSE: Quality, Safety and Environment

WAD: Waiting Area for Decision

AHP: Analytic Hierarchy Process

VSM: Value Stream Mapping

OIW: Ordinary Industrial Wastes

SLP: Systematic Layout Planning

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Foreword

Origin of the project

The tasks of maintenance realized in mechanical workshops are not executed in the best conditions. As a result, the performance drops which consequently influences customer satisfaction. This project was elaborated in order to potentially restore the prestige of CMM workshops.

Motivation

As it helps reduce waste, defects, and unnecessary costs, the project is led by a desire to improve working conditions in mechanical workshops but also to go further than a simple re-organization and cleaning operation. The main motivation of the project is to facilitate the daily work of mechanics.

Requirements

To reach the goal of the project, knowledge in how to process improvement, how to manage a project, and how to include the standards of security are required. Moreover, to understand easily the fulfilment of the project, knowledge in mechanics is preferable.

Introduction

Subject and problematic

This project will focus on the spreading of organization methods into pre-defined workplaces. These methods are based on rules and standards that may be respected and adapted to the environment in which they are applied, because all workshops have the same objective but not the same organization. What are the best ways to improve workshop process? Are the chosen solutions sustainable in the future?

Project goal

CMM has noticed a lack of organization in its mechanical workshops and wants to raise the level in those workshops in order remain the world's leader. The aim of this project will be to find adequate solutions to increase the quality of work of the employees, and to prove that they are beneficial for the overall performance of workshops.

Scope of the project

This report deals with an approach initiated through a panel of CMM mechanical workshops. Technics will be introduced to several sites. However, the complete study will not be given for each one as only necessary examples will be used to illustrate the details of the solution applied and the corresponding results.

1. Background of the project

1.1. Initial situation

Even if Colas, the world leader in road construction, is very well placed in the ranking of French construction companies, the group is only in 7th place behind the giants Eiffage, Vinci, or Spie. In 2018, its turnover on the French road sector amounted to 462 865 030 €, which is less than a third of what Saipem was able to produce at the top of the ranking (1 490 507 000 €). Ambitious to gain even more places in the market, the company Colas wants to further develop the activity in the French territory by growing each of its 6 subsidiaries. For that, each of Colas' areas of action has been reviewed and the revision of mechanical workshops for construction vehicles is part of the list of important activities to support in order to catch up with competition. Indeed, vehicle maintenance activity produces the highest share of the group's turnover, ahead of road construction activities. A mission was therefore provided for an improvement of the mechanical workshops in each French subsidiary of the group.

1.2. Incentive for the project

With regard to the Midi-Méditerranée subsidiary, CMM holds under its control more than 30 sites spread into all its territory of action, to maintain every day the large vehicle fleet of each agency. Recently, CMM has noticed many unfortunate events, as delays into the maintenance operations, or employee injuries. CMM suppose that a lack of organization could be at the origin of these events, that is why our services were engaged to run this project. It is true that mechanical workshops are currently fulfilling their role very well, but CMM and all the other subsidiaries are involved in the ISO 14001 standard, which requires compliance with criteria some of which are specifically related to the organization of the workspace, such as those given below:

N°	THEMES, REQUIREMENTS AND GOALS	EXPLANATIONS BY THE ENVIRONMENT DIVISION
79	The onsite holding stock for waste products may not exceed either one year or 1.5 times the normal collection amount (as defined in a written document; it may be a drum, a palette, a truck box, etc.). Inert waste (concrete, gravel, etc.) is exempt from this requirement.	Our sites are not regulated in terms of waste storage unless otherwise specified; in addition, no provision is made for risk analysis with regard to growing stockpiles of our waste. It is consequently very important to ensure that we do not allow excessive quantities of waste to accumulate through lack of management or repeated negligence, as this would both be against regulations and create an uncontrolled risk. The normal collection amount is typically set out in the contract with a waste management company (type of container for each type of waste, minimum quantity of waste required for collection, etc.). This procedure may be specified in the environmental analysis (For sites ISO 14001 certified), waste management instructions, etc.
91	- risks identification and assessment	Risk identification and assessment may be carried out as part of an environmental analysis (For sites ISO 14001 certified). They may take into account documents such as the impact study or hazard study carried out, for example, during the application process for the PTO and/or other information collected at that occasion.
92	- implementation of preventive measures	After assessing risks, it is necessary to implement actions both to prevent these risks and to minimize their impact in the event they occur. Identifying a risk without taking further action is not an option! The risk assessment results and the risks prevention and minimization measures can be specified in the environmental analysis (for ISO 14001 certified sites).

Table 1: Examples of organizational requirements for ISO 14001 standard

Thus, to be up-to-date during audits but also in a concern for improving performance, the launch of such a project is necessary for the company.

1.3. Technic chosen

In the continuity of this report, it will be shown that gaps appear in basic aspects of the workshop's organization, revealing many areas of inefficiency and affecting different fields of application. What is the most adapted method to reach the objective of such a project? A methodology that adapts to the whole workshop, without sparing one area of the others, is necessary. It would seem preferable to apply the famous 5S methodology before considering other techniques for organization improvement. After several interviews with the CMM managers before the beginning of the implementation, this technique attracted particular attention for many reasons:

- 5S is a method by which we can track workshop compliance with processes and procedures.
- It incorporates all of the Colas Safety & Environmental processes to monitor compliance.

- 5S is a set of techniques that provides a standard approach to workplace organization within Lean Operations.
- It is the starting point for implementing Lean principles and leads to a Continuous Process Improvement environment, while creating a workplace where quality services and products are provided with pride.
- 5S represents five disciplines for maintaining a visual workplace based on “Lean Concepts” with safety and environmental stewardship.
- It constitutes a process designed to organize the workplace, keep it neat and clean, eliminate waste, maintain standardized conditions, and instill the discipline required to enable each individual to achieve and maintain a World Class work environment.

5S is a solution to make organization and safety a part of the mechanic’s daily routine. It allows every employee to participate in the methods and processes within their own organization while maintaining individual work responsibilities. Originally, the 5S are a succession of steps, which run across the entire organization to improve. As a response against the lack of organization, its relatively low deployment cost is an advantage too for the budget of the different agencies. It does not require any particular experience into workshops to be launched. The transfer of knowledge is done through experimentation in the field at the time of deployment, which gives the facilitator of the method a great deal of autonomy.

However, the 5S is one separated technic in its own right, but its application seems to be based most of the time on visual criteria. In order not to perceive this method as a simple storage and cleaning in the work area, other analysis and decision support tools can be used, to support the implementation of 5S and make it more effective. Each thing should have its place, and we will see in the continuation of the project that this is not always the case in the workshops studied. Thus, it seems necessary to integrate essential techniques of organization into the 5S. First, Value Stream Mapping of the general maintenance process, performance ratios as OEE, the 5 Why analysis, followed by Pareto and Ishikawa diagrams could help to identify the less obvious sources of losses and the expectations of the 5S application. Then, improvement methods as Analytic Hierarchy Process, Systematic Layout Planning and linear programs may bring support into the proposals of solutions against these loss in performance, linked with the 5S approach. A presentation of these 5 famous pillars, including these additional ways to ensure good results are presented on the following section.

2. Theory

2.1. Functionment of the 5S methodology

Its origin comes from the Japanese culture which has evolved through years to respond to companies' requirements. First, the 5S methodology gets everyone involved in designing and developing a clutter-free and well-organized workplace. Secondly, maintenance of the newly organized area is an integral part of this process. However, 5S differs greatly from other methods by emphasizing prevention of the mess in the first place rather than constant cleanup. Finally, implementation of 5S will make it much easier for mechanics to perform their job. Which means they'll be able to devote more time and attention to continuously improving products and processes.

The first pillars of the 5S quantify the disorder and try to reduce it, while the others are more focused on workplace processes.

- **1st S : Sort**

This first step in the approach is to select all the items considered as unnecessary or unusual for the good realization of the tasks. In the case of the project, surplus stock is the main target, but it also considers obsolete items, unnecessary tools and equipment for the workers during their daily tasks. The idea is to keep essential things, in relation with the actual vehicle fleet of the workshop.

- **2nd S : Straighten**

The aim of the following step is to create and achieve an efficient working environment layout by placing items and materials in specified locations for easy accessibility and functionality. The characteristics of each item have to be studied, and their final placement must not be ordered randomly.

- **3rd S : Shine**

The third concept deals with the cleanliness of every mechanical workshop's location. A clean working environment is a motivating factor for employees, it removes a part of the risk and create a better climate of work, replacing old furniture by new ones and make them more pleasant to see. Moreover, this step is very important because in the end it helps identifying mechanical failures.

- **4th S : Standardize**

This concept ensures that the first three concepts become a continuous and maintained practice in the maintenance workshop, by establishing codes and specific processes for workers. The normalization is the key for progress.

- **5th S : Sustain**

It is probably the hardest step to go through. “Sustain” is essential to ensure the 5S success for a long time. People who apply this methodology must focus on keeping these changes, continuing the improvement and forgetting the old technics. Planning and controls have to be established during this final step.

2.2. Tools for analysis into process performance decrease

2.2.1. Indicators

- **OEE and ratios**

A process is composed of activities, which are composed themselves of tasks: mechanicals cannot easily find parts or tools if the storekeeper has not stored them rightly. Yet, the same goes for the storekeeper who cannot store efficiently parts if the workshop manager has not realized the expected order for the parts needed. The performance can be controlled thanks to indicators which take into account the critical operations of this diagram.

The OEE indicator (Overall Equipment Effectiveness) is used to compute this performance and identify potential sources of improvement for a process. It is composed of three other indicators: the Availability rate, the Performance rate, and the Quality rate. The multiplication of these three rates gives the OEE value **[1]**. Generally, the two first ratios are the most essential for the study of performance. Indeed, for mechanical activities for example, the quality has the less impact on the indicator value. Indeed, when the process ends for a vehicle, it means its proper functioning has been checked by mechanics after operations and that it can be requested for the active construction sites ; if not, the vehicle in question is not scrapped, mechanics have to restart a typical process and the works undertaken are then taken into account as additional operating time.

OEE is the ratio of Fully Productive Time to Planned Production Time. Schedule loss is not included in OEE calculations since there is no intention of running production. A loss designates anything that involves the misuse of resources in a work environment. There is a lot of different kind of losses. The next part of the project will identify the main sources of losses that decrease the final performance. What means this OEE value? In theory, a World-Class OEE score should be 85%. In practice, the generally accepted world-class goals for each factor are quite different from each other:

- An OEE score of 100% is perfect productivity: operations are successful and fast, without any stops in the process.
- An OEE score of 85% is considered world class for companies. For many, it is a suitable long-term goal.
- An OEE score of 60% is fairly typical for companies but indicates that there is substantial room for improvement.

- An OEE score of 40% is not at all uncommon for companies that are just starting to track and improve their working performance. It is a low score and, in most cases, it can be easily improved thanks to straightforward measures.

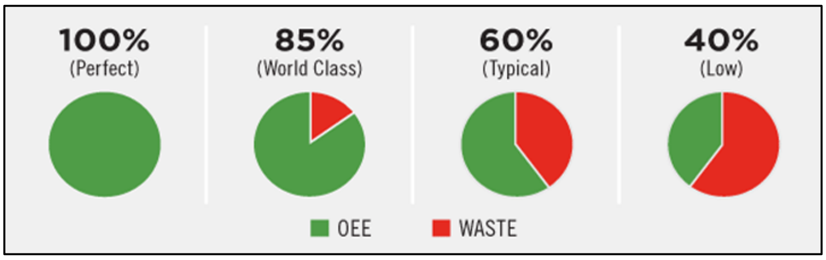


Figure 1: Evaluation of OEE ratio

2.2.2. Methods of identification

- **Value Stream Mapping**

VSM involves tracing the physical flow of materials, parts or products along a process through all the steps. This mapping consists of universal pictograms, thanks to which it is possible to identify malfunctions and potential improvements of the process **[2]**. Generally, a timeline indicates the lead time of the process (Lead Time), this line will not appear in the next flow maps as the vehicle maintenance process does not have a fixed completion time due to the wide variety of achievable tasks.

- **Pareto – 5Why – Ishikawa**

After the identification of the flows in the workshops, leading a survey seemed convenient to find different ways to increase the performance in order to reach the goal of the project. Three management tools can be used one after the other in the frame of the 5S development, it is first the Pareto diagram, followed by a 5 Why analysis, and the Ishikawa diagram.

To improve the process performance, occurrences of failure or problem have to be quantified thanks to surveys. The Pareto diagram represents occurrences by placing into columns the most frequent ones on the left, designated as the "head" of the Pareto, and the rarest ones on the right which are considered as its "tail". Thus, the most important ones, those which have the worst impact on the process, can be identified. According to the theory based on observations, about 20% of the causes would be responsible for 80% of the defects **[2]**. If the opposite effects are apparent, their original causes are not always obvious for the 5S facilitator. Additionally, the 5Why analysis is composed of five recurrent questions, called “Why?”. To identify the original causes and their sub-consequences one needs to answer each “Why?” with a rational answer. To finish, a fish thorn diagram shows all the data from both of the previous studies in order to present all the causes of the decrease in performance and quantify it. The Ishikawa diagram structures the identified causes of the effects generated based on five main factors: Environment, Workforce, Material, Method, and Equipment **[2]**.

2.3. Complementary techniques for improvement

- **Quantitative Methods for Organisation**

In this project, mathematical programming concepts will be used to configure physical/organizational systems seeking to minimize or maximize results that depend on workshop-specific variables and restrictions. The basic tool to solve this type of problem being the solver provided by Excel, the functions entered in the program will have to be linearized.

- **Analytic Hierarchy Process**

The AHP method is a structured technique for organizing and analyzing complex decisions based on mathematics and psychology. In particular, the AHP method is used to make decisions based on multiple criteria and it consists first in evaluating these criteria according to their preference for each alternative. Then it will develop the comparison matrices of alternatives and criteria in order to obtain the priority matrices. This results is a vector of overall priority, so the highest value corresponds to the most plausible alternative **[5]**.

- **Systematic Layout Planning**

SLP is a central technique of relationship diagramming for space optimization**,** where each activity-area is drawn to scale and thus showing the relative size of each area, as well as its best-related position. The steps to follow during this method are first to draw the relationship diagram between all the concerned equipment, then to value the space necessary for the correct operation of each component and finally to develop the solution according to the two previous factors. Additional quantitative factors, like for example the cost of moving, can be added to the study for the final distribution choice **[6]**.

3. Analysis

3.1. Preliminary analysis

3.1.1. Value Stream Mapping

The workshops and the offices recently seemed to be still hermetic to each other. However, some of the practices of one are necessary for the functioning of the other. In terms of workshops improvement, the notion of process is fundamental. Thus, in companies with these two entities, it is preferable to optimise the overall process rather than trying to optimise office tasks and the workshop separately. In most cases, the administrative tasks performed by the workshop manager oversee the physical tasks, like in the following succession of activities, which reads from left to right:

Task	Manage orders	Order parts	Replace vehicle parts	Check functionment of the vehicle	Fill the vehicle service manual	Manage daily reports
Type	*Administrative*	*Administrative*	*Physic*	*Physic*	*Administrative*	*Administrative*

Table 2: Example of succession of administrative and physic activities

The overall performance of this process is not solely related to the performance of the workshop. The concept of maintenance is increasingly extended to the administrative part, before, during and after the repair. Thus, the customer, who in the project is the driver of the vehicle, remains in uncertainty as to the date of the delivery of his vehicle. Overall performance can only be achieved through one organization per process, with all departments and tasks aligned to serve the client efficiently. Value Stream Mapping is used to visualize the physical flows and the reversal flows that contribute to the creation of value in the process, as well as to discriminate between value-added tasks and non-value-added tasks. The VSM of the functioning of the general workshop is given in order to separate these two kind of tasks and determine the scope of action of the 5S implementation on the process:

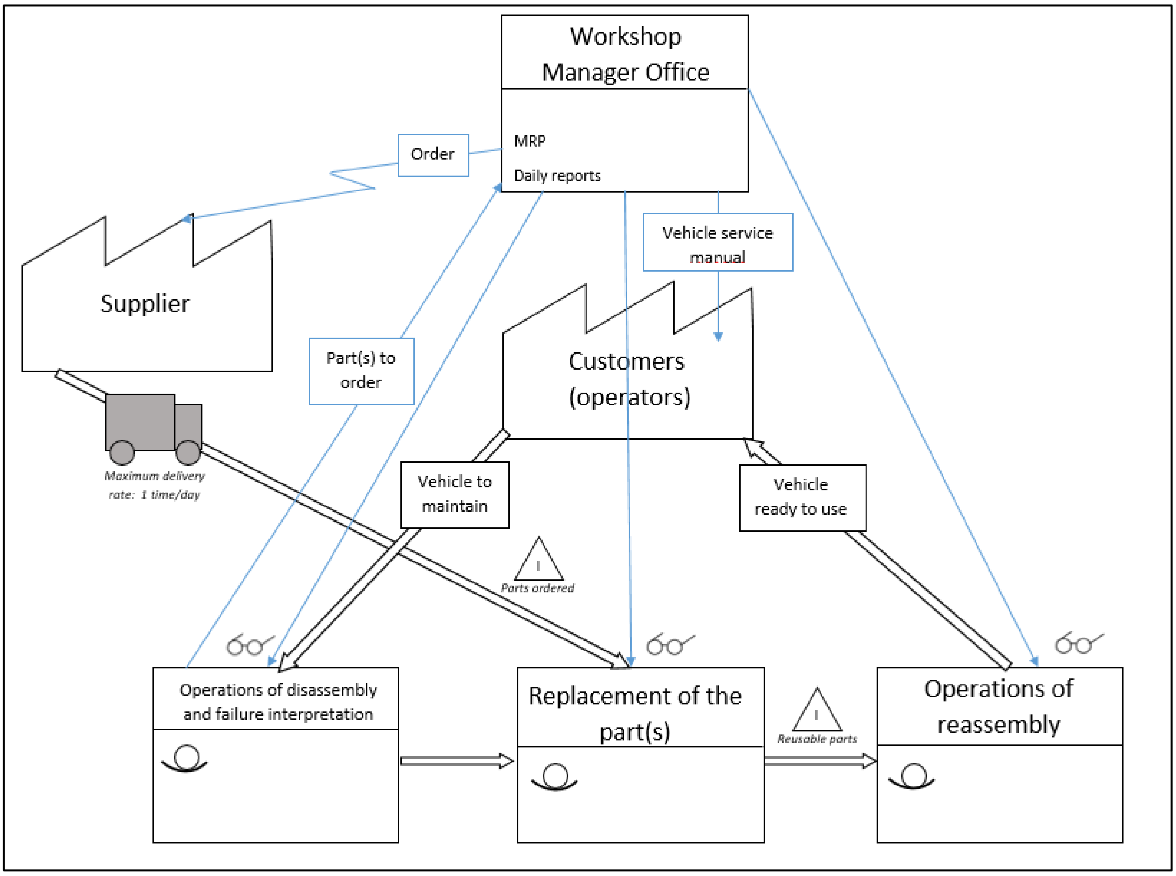


Figure 2: VSM for a classical maintenance workshop

Into this process, several entities may cause a decrease in the overall performance of a workshop. However, some are not included in the project's proposed enhancement, the VSM allows us to observe quickly the limits of the sections to improve. The supplier for spare parts or tools is external to the society, the delivery time does not depend on an intern modification of the workshop process. Moreover, the incoming orders, issued by the original mechanics and then validated by the workshop manager, are entirely linked to the communication system used by the CMM agencies. The only area that can be reached by the project itself is in the last part of the VSM, which is composed of the essential operations of the site: the dismantling and reassembling of mechanical elements.

In order to obtain good results in the further development of a workshop, it will therefore be necessary to concentrate mainly on improvement of the conditions during vehicle maintenance operations, which is above all the main role of this activity.

3.2. Identification of initial causes

3.2.1. Global process for the vehicle maintenance

The final performance in vehicle repair and maintenance depends on the sequence of tasks performed by mechanics, storekeepers, and workshop managers. These three categories of staff all have different roles that remain linearly linked to the time. A traditional vehicle maintenance process, from its reception in the workshop to its exit:

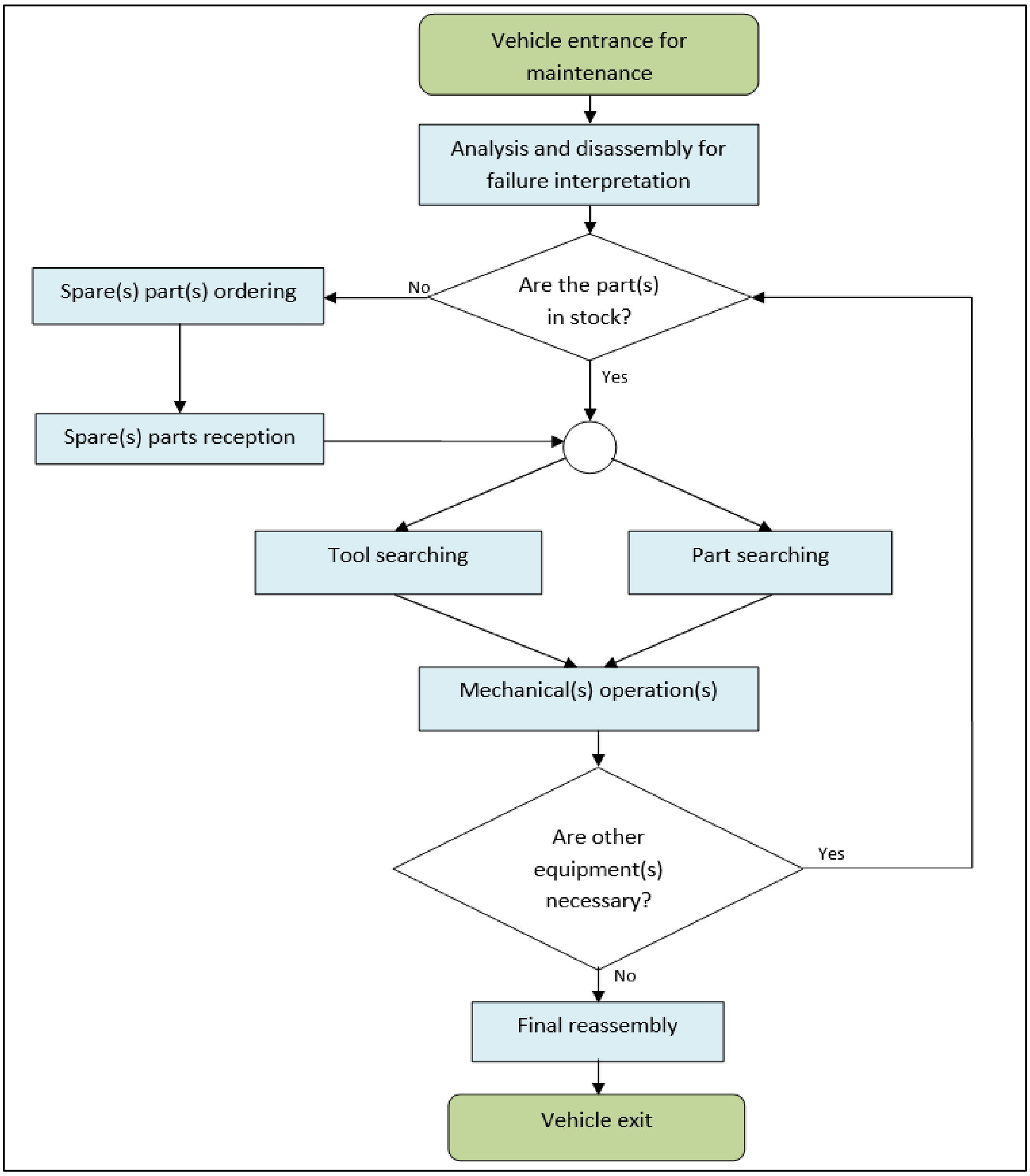


Figure 3: Process diagram for vehicle maintenance

This process diagram is an example of a classic situation, that is to say when an occurring failure is identified clearly and at the beginning of the process by the staff, but also when there are no additional hidden failures discovered during the fulfilment of the activities, for example during preventive maintenance to change all the filters of a vehicle. The mechanics' working days are marked by this diagram, and their operations, included in the dotted loop, are repeated as many times as necessary to carry out a task on a vehicle.

3.2.2. OEE analysis

For an entire classic working day, the time for each activity led by one employee are collected at the beginning of the project, before the implementation of the methodology, and then organized according to their nature:

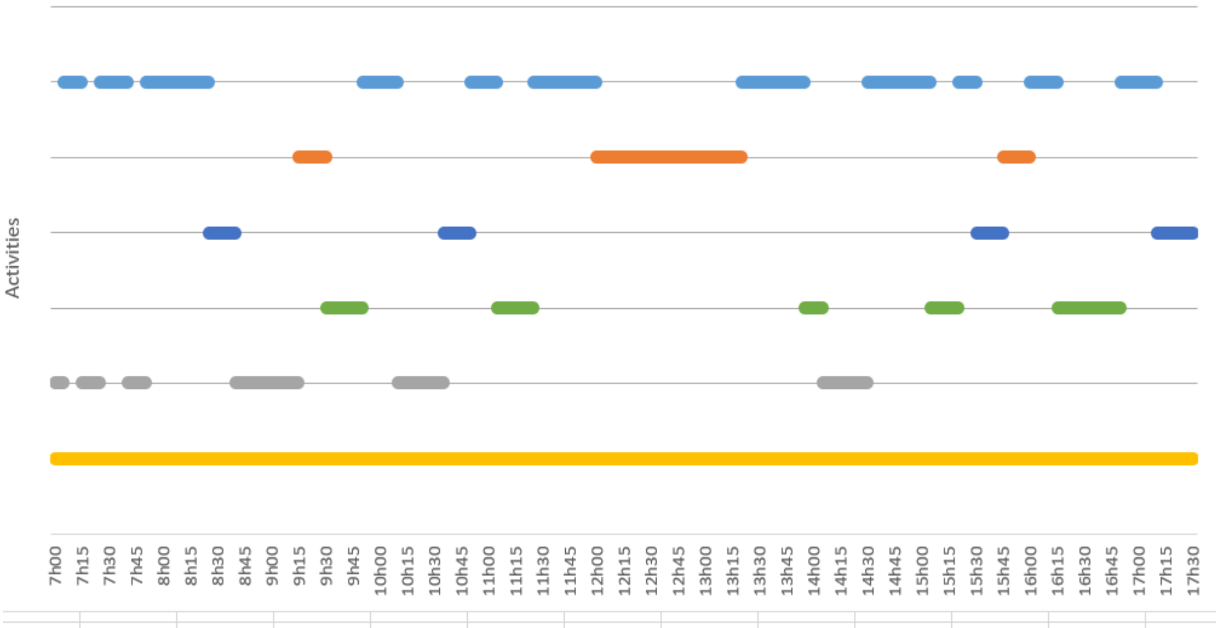


Figure 4: Time repartition on a working day

Figure 5: Legend for time repartition

During the whole working day tested and schematized on the graph above, the worker has been working on 6 different vehicles, from 7.00am to 5.30pm, including breaks. The following table gives the total value for each time factor and operation led on these vehicles, then the OEE is computed thanks to the three ratios:

	Value	Unit
Total time in a day	10,5	*h*
Planned operating time	8,67	*h*
Operating time	5,18	*h*
Net operating time	4,1	*h*
Good operations	6	*u*
Total of operations	6	*u*

AVAILABILITY	0,597
PERFORMANCE	0,792
QUALITY	1

OEE	0,472895

Table 3: Study for OEE into workshop

The efficiency obtained here is quite weak. An actual OEE value computed at 0,47 is lower than the satisfactory level according to the rating scale. However, it is not the worst situation for this CMM mechanical workshop taken as example, but it is not the best as well. The ideal case is to increase this OEE score from 60% to 85% at least, by improving resource availability, process performance or both at the same time. The quality factor is already at its maximum level, the objective is of course to maintain this asset during the 5S implantation.

Depending on the OEE computed previously, the project seems to focus mainly on the **availability of resources** first, which are directly related to movement, latency and inventory losses, then on the **performance field** linked to bad processes or equipment failures. In the end comes the **quality of work**, which offers indications about the way of working and is related to how the employees are realizing maintenance thanks to the knowledge from their professional training. This ratio is more difficult to value in the 5S approach, because it does not depend directly on the work environment. On the example above, availability is the first of the three OEE factors to be calculated and it accounts for when the process is not running. On the contrary, the second factor is the performance, which accounts for when the process is running slower than its theoretical speed. It was noticed that 40.3% of the planned operating time is finally wasted as unavailability, 20.8% of the operating time is not dedicated to real working operations. However, all operations were successful because of a quality ratio equal to 1. The lack of movements or storage have a more important impact on the OEE indicator, while the waste of time due to the performance of the processes is less significant on its final value, since the quality of work has no impact on the final OEE value here. Why is the operating time so reduced in the end?

3.2.3. Primary approach with Pareto diagram

A survey using a Pareto diagram can be set up to determine the main causes of the drop of performance in the mechanical workshops, in order to focus the project's potential improvements about this topic. First of all, the most common occurrences of each phenomenon are identified and grouped in a summary table. Ten situations involving possible losses during the project are cited, and named from A to J. Each one is able to decrease the final OEE value: phenomenon in red are impacting the availability, the blue ones relate to the performance of the employee while the green ones deal with the job quality. Thanks to the repartition of time in an employee working day collected previously, it is possible to arrange in the table the frequency and the total duration in hours for each phenomenon on the working day studied.

Case	Description	Frequency	Total Duration [h]	%	Cumulative %
D	The mechanic spends too much time bringing back a spare part from the storage area	5	01:20:00	32,0%	32,0%
A	Mechanic have to quit the span to search a tool	3	01:00:00	24,0%	56,0%
B	A mechanic has no work in progress, or a tool is not available	2	00:45:00	18,0%	74,0%
C	The tool/part searched is finally not in storage	1	00:25:00	10,0%	84,0%
G	The source of the problem identified at the beginning is wrong	1	00:20:00	8,0%	92,0%
E	A problem occurs during a maintenance (a tool/part break, a tool battery is empty, …)	2	00:15:00	6,0%	98,0%
F	The tool or equipment used is not the right one	1	00:05:00	2,0%	100,0%
H	The part ordered is not adapted to the vehicle	0	00:00:00	0,0%	100,0%
I	The time dedicated to a task is wasted because it failed	0	00:00:00	0,0%	100,0%
J	A mechanic has to stop because of injuries during a task realization	0	00:00:00	0,0%	100,0%
	TOTAL	0	04:10:00	100,0%	100,0%

Table 4: Identification of losses on a classical working day into mechanical workshop

The percentage of time wasted for the entire day is finally computed. The most important losses that come out of the lot are those due to the difficulty to find some parts by the workers, while the less impacting ones are the criteria of quality. This means that on the total work time, employees spend more time searching for a tool or spare part than solving problems related to equipment failures during the vehicles maintenance. The next Pareto diagram represents these occurrences and a cumulating row appears to indicate the cumulative relative importance of the columns. Thanks to this diagram, the 5S facilitator can easily take decisions and give priorities to the most important actions. Here is the diagram adapted on the study:

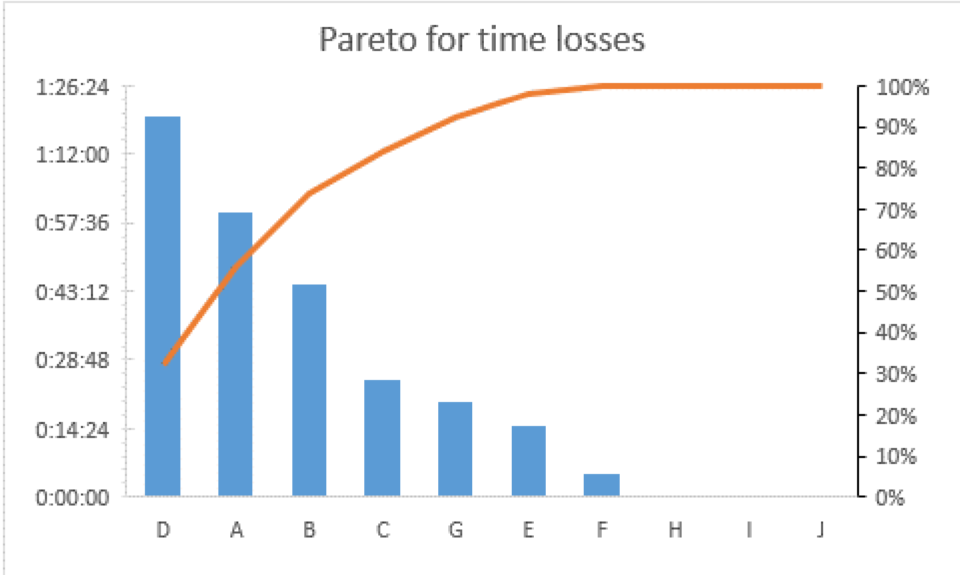


Figure 6: Pareto diagram with cumulative row

By searching the best way to reduce defects, one may wonder: is it better to cut off the head or pull the tail of the Pareto diagram? To achieve significant results, it is better to focus on Pareto's head because it is where actions have the most influence. On the other hand, acting on Pareto's tail allows to solve small and low-cost problems of the mechanical workshops faster; problems that are often less considered by the workshop managers, but have their importance. **[5]**

Based on the previous OEE final value, significant results should be brought to the project in order to reach an acceptable threshold by working on the most encompassing aspects identified.

3.2.4. Comprehensive analysis with the 5 Why and Ishikawa

The main source of losses quoted in the previous OEE study has to do the equipment availability. In effect, this project has been engaged because of a lack of organization in the storage efficiency. Indeed, the organization of the storage is often lower than the level expected by the workers which increases considerably the search time as long as the object sought is always present inside the workshop. This represents the biggest losses according the Pareto diagram elaborated. How can spare parts and equipment, supposedly ordered at the beginning of the process, suffer from organizational problems afterwards?

Internal causes for the main sources of losses are going to be identified thanks to specific methodologies in order to solve the problem in accordance with the 5S objective.

We will use the 5 Why procedure coupled with an Ishikawa diagram. But before it is necessary to perform a more accurate searching measurement than the one made for computing the OEE value on a whole day. This preliminary analysis is known generally as the “Martian Test” or the “30 second Test” and measures the necessary time in a manufacturing place to return a randomly requested item **[3]**. Firstly, a series of tests will be carried out beforehand in order to compare it with the measures that will be made after having overcome the problems found earlier.

Part requested	*Mechanic 1*	*Mechanic 2*	*Workshop manager*
Gazole filter for Mecalac 12 MXT	0’56’’95’’’	1’04’’13’’’	0’55’’50’’’
Brake Cleaner spray	0’25’’28’’’	0’33’’02’’’	0’22’’29’’’
Bolt for rake blade	0’54’’82’’’	1’17’’80’’’	1’18’’12’’’
Left mirror for Renault Master III	1’19’’03’’’	1’10’’71’’’	1’35’’66’’’
Paver controler pad	0’59’’57’’’	1’22’’69’’’	1’24’’28’’’

Table 5 : Timing records for the initial “30 seconds Test”

According to the results in the table above, almost every actor failed to find all the parts requested in time. Only two people, followed closely by the third one, succeeded to find the “brake cleaner spray” in less than 30 seconds. This equipment is frequently used in workshops so the staff tested may already have the habit of searching this kind of element in the storage area. This could explain the low time recorded for this part especially. If we look at the other parts requested, the times recorded highlight an issue in the storage arrangement. In the frame of the problem enunciated, which is the “elevated time for bringing back a spare part from the storage area”, the 5 Why technic is now applied and five other causes are identified from the initial cause, flowing one after the other in a logical order to find at the end the most profound one which led to this temporal waste. The most profound causes related the project are highlighted in green. They are the ones that can be improved under the application of 5S. However, some of the original causes identified thanks to the 5 Why are not fundamental, so they are not in the project scope; they are highlighted in red. These causes are not under the control of 5S.

	Causes	Problems
WHY	Mechanics have doubts about where to look for the part	Why do they have doubts?
WHY	The storage location of the part searched is not obvious	Why is the location not obvious?
WHY	They have to search for parts in multiple potential locations before finding the right one	Why do they have to search the part at several locations?
WHY	The location of the part is not easily recognizable from a distance	Why isn’t the location of the part easily recognizable?
WHY	There is a leak of information	

	Causes	Problems
WHY	Mechanics have difficulties to recover the part	Why do they have difficulties?
WHY	Parts are not easily accessible	Why aren’t parts easily accessible?
WHY	It is too dangerous for mechanics to take out the part alone	Why can't they take out the part alone?
WHY	Mechanics need help from other people or from a lifting device to catch the part	Why do they need additional help to catch the part?
WHY	Parts are too heavy or too voluminous	

	Causes	Problems
WHY	The time spent going back and forth from the storage location of the part is to important	Why is this time too important?
WHY	Mechanics have to walk great distance to bring back a part	Why do they have to walk a lot to bring back a part?
WHY	Parts that are less solicited are closer to the span than parts that are more often solicited	Why are solicited parts further than less solicited ones ?
WHY	The journey is not optimized	Why isn't the journey optimized ?
WHY	Frequently used parts are not located close of the working area	

	Causes	Problems
WHY	Mechanics can't find the part in the storage	Why can't they find the part in the storage?
WHY	The part was delivered but is nowhere in the storage	Why isn't the part in the storage?
WHY	The part is always on the parcel receiving area	Why the part is always on this parcel?
WHY	Mechanics or the storekeeper forgot to store the part in the corresponding rack	Why did the staff forget to store the received part?
WHY	There is no follow-up after receiving the part	

	Causes	Problems
WHY	It is not possible to find the part in the workshop	Why is it not possible?
WHY	The part was not delivered	Why the part was not delivered?
WHY	The order has not been accepted yet	Why the order is not accepted?
WHY	The workshop manager has not finalized the order	Why the order is not finalized?
WHY	We don't know	

	Causes	Problems
WHY	Mechanics can't find the part in the rack	Why can't they find the part in the rack?
WHY	They can't see the part directly	Why can't they see directly the part?
WHY	The part was hidden by others	Why is the part hidden by others?
WHY	The parts are overflowing in the rack	Why are there too much parts in the rack?
WHY	The rack dimensions are too small or several categories of parts are stored in the same rack	

	Causes	Problems
WHY	Mechanics have difficulties to find the part in the storage	Why do they have difficulties to find the part in the storage?
WHY	The part is not easy to identify	Why isn't the part easily identifiable?
WHY	Its reference has been removed from the packaging	Why has the reference been removed from its packaging?
WHY	It is due to bad storage conditions	Why are the conditions of storage bad?
WHY	There is a leak of liquid (oil, fuel, water…) or a wrong storage temperature (cold/hot, sun exposure…)	

	Causes	Problems
WHY	Mechanics have difficulties accessing the corresponding rack	Why do they have difficulties accessing the rack?
WHY	The access is blocked	Why is the access blocked?
WHY	There are boxes lying on the ground	Why are there boxes lying on the ground?
WHY	Boxes of parts are put down on the storage ground waiting to be properly stowed	Why are these boxes always waiting to be properly stowed?

WHY	The staff who let the boxes was in a hurry, or was lazy to store them	

Table 6: Main causes tracking thanks to 5 Why tables

Among all the causes put forward, some are dealing with the characteristics of the parts stored, while others are relating to bad habits in the workshop process, or to other reasons. To delineate a range in this cluster of topics, each of the identified causes will be grouped into a specific family constituting the Ishikawa diagram. In addition, a rating system has been set up in order to prioritize the actions to be carried out concerning the general improvement of the dysfunction studied. The hierarchy of causes starts from the less important **(- -)** to the more important **(+ +)** passing by an average mark **(0)**. The different marks have been attributed with the workshop members and the 5S facilitator of the project. The Ishikawa diagram is available on **Appendix 1**.

By looking at the diagram, it appears that the main causes of time loss are due to the workshop environment and to storage methods. For the first reason, the actual display conditions seem inefficient for workers. The other reasons are more focused on the organization of the workshop, involving the frequency of utilization for all equipment. In a nutshell, the 5S methodology will be useful to enhance the worst conditions of the environmental and technical fields as described into the diagram.

3.3. Additional causes

Today, safety has become a top concern for businesses. In fact, the standardization of processes as advocated by the 5S method tends to reduce the sources of risk in carrying out tasks in a mechanical workshop. Of course, this is only a matter of improving the processes, but the working environment remains dangerous if only the improvement of working methods is considered. To identify risks, a survey involving workshop members is made at the beginning of the project to gather information on the non-obvious sources of risks of a workshop. The most rational of theses ones are grouped into the following heat map from the least important to the most serious and from the least likely to the most frequent according to the opinions received:

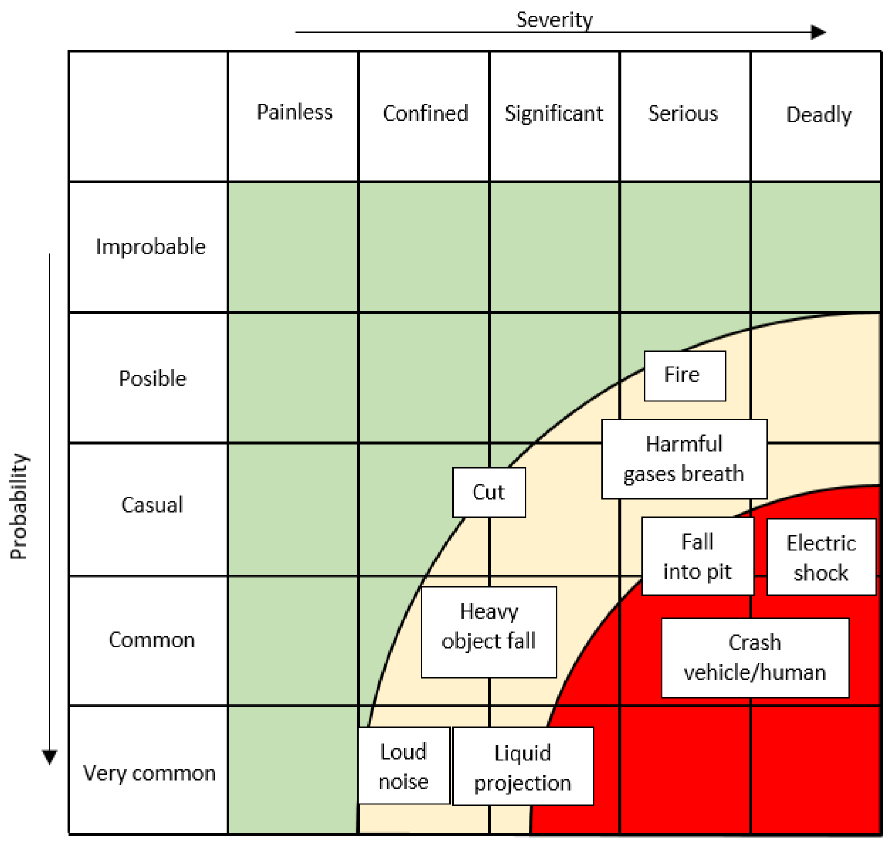


Figure 7: Matrix of risks on the workplace

Injuries due to do burns, cuts, big noises, object falls, and projections are the most minor incidents among those identified. They are at the edge of the matrix's light impact zone. However, special attention should be paid to the most significant sources of accident focused in the "warmest" area of the matrix : electric shocks that are invisible but violent, falls in the pit which remained open or even the inevitable crash between pedestrians and vehicles have to be considered in this project not to forget improving working conditions at the same time.

4. Proposals for conditions enhancement

An improvement of the storage environment in the workshops seems to be considered as the most important point to enhance in order to obtain better performance in the vehicle maintenance. The following points are dealing with proposals of storage processes, material's storages and display improvement according to the previous analysis led into the different workshop areas.

4.1. Methods proposals

4.1.1. Equipment availability

4.1.1.1. Context

The second most important source of losses identified in the workshop performance is that mechanics spend too much time leaving the span with the maintained vehicle, sometimes to search just a classic wrench. Most of the very common small tools used for disassembling and reassembling parts are stored in a mechanic's cart, which mechanics move where they want on the workplace. Often, workshops possess only one cart for the entire staff. The most common small equipment findable into this mobile box could be open-end and socket wrenches, screwdrivers, pliers, hammers, small consumable items, etc. In order to reduce as much as possible unnecessary movement between the spans, it was thought into this project's frame to elect a storage location for this cart as efficient as possible. In term of 5S, the aim is not to buy and distribute one mechanic's cart for each member of the team, but to make actual resources as accessible as possible for everyone. In addition, it should not be forgotten in the study that this cart can also be used for off-span works, as in the boiler room or on workbenches when vehicle components are dismantled for a more precisely attention. To find the optimal location of the cart in the workplace, it was considered as the best solution to resolve a mathematical program, using variables, an objective function and requirements specifics for the workshop studied.

4.1.1.2. Analysis of the environment conditions

To lead this study, one workshop among others was taken as example to present the technic to apply in order to find the best arrangement. It has a rectangular structure, with a total area of 20x33 meters **(1 and 1')**, and is composed of four spans: three of them are continuous with two entrances on both sides of the workshop structure, while the last one only has one door **(2 to 7)**

Firstly, the main areas of activity were identified. To simplify the problem and adapt it to each workshop, the first step was to identify the center of gravity of each span, which are likely to be the areas where activity is most concentrated due to the random entry and exit of vehicles. The measure of distances is considered by the Manhattan model, with (X;Y) coordinates for the cart's location, and the scale chosen on the map is 0,5 meter/square. So, on a simplified workshop map showed on **Appendix 2**, the points (8;10), (13,5;10), (19;10), (24,5;5) are respectfully the center of each span.

Secondly, it is evident that other secondary work areas are present outside the main spans. This may include, as in the case of the workshop studied, space dedicated to general work on a work bench, boilermaking work, or work requiring careful disassembly. That is why the points (2,5;7) and (29;17,5) indicate respectfully the location of boilermaking area and workbench area on the map from **Appendix 2**.

Some of the areas identified may be used more often than others. The establishment of a utilization ratio can then be useful in determining the importance of each of these areas for future optimization. Indeed, it is clear that mechanics do not move at the same rate between each work area. Therefore the utilization coefficients for each area were chosen in the following table, based on a return of personal experience of employees:

Working area (i)	Span 1	Span 2	Span 3	Span 4	Boilermaking works	Works on workbench	**TOTAL**
Utilization	0,15	0,3	0,15	0,1	0,25	0,05	1

ratio U(i)							

Table 7: Utilization ratios among working areas

This workshop is composed of a rectangular structure, the surface of which is composed of a general part dedicated to the maintenance of vehicles. In the case of a workshop with more complex structures, such as wall separations where the employee would be forced to go through a door in order to pass from one work area to another, it would be necessary to amend the program to take into account any restrictions on the movement of mechanics. The occupation of vehicles on the spans according to customer demand is a totally random event whose study does not fall under this project. Since not all spans are occupied at the same time according to the mechanics, the mechanics are free to cross the main space from side to side, making straight movements between the different working zones. All of this involves the installation of a storage area for the mechanic's cart, which must not interfere with the entrance or exit of vehicles in the middle of the spans. As the spans must remain free for an eventual entrance of vehicles, the following requirements will be included into the program:

- $0 \leq X \leq 33$ and $0 \leq Y \leq 20$ due to the workshop structure **(1 and 1')**
- Span 1: $|X - 8| \geq 2 \equiv MAX(X - 8; 8 - X) \geq 2$ **(2)**
- Span 2: $|X - 13{,}5| \geq 2 \equiv MAX(X - 13{,}5; 13{,}5 - X) \geq 2$ **(3)**
- Span 3: $|X - 19| \geq 2 \equiv MAX(X - 19; 19 - X) \geq 2$ **(4)**
- Span 4: $X \geq 26{,}5 + \mathcal{E} - M_1 Z_1$ $(\mathbf{5})$; $X \leq 22{,}5 - \mathcal{E} + M_2 Z_2$ $(\mathbf{6})$; $Y \geq 10 - M_3 Z_3$ **(7)** with $Z_1 + Z_2 + Z_3 \leq 2$, $M_1 = 26{,}5 + \mathcal{E}$, $M_2 = 10{,}5 + \mathcal{E}$ and $M_3 = 10.$

Formulas of requirement

The 3 binary variables Z_1, Z_2 and Z_3 , including the element Ɛ equal to 1×10^{-6}, were created in order to linearize the Span 4 expression. Indeed, strict inequalities are not allowed in mathematical programming, and the Span 4 implies inequalities of this type because of its specific delimitation which only crosses the workshop by half so that the maximum distance to the identified work areas is minimized.

4.1.1.3. Program realization

It is therefore possible to model a program minimizing the maximum distance of identified work areas' essential points for the movement of employees in the workshop. To begin, the coding elements to be created are:

Variables:

- X: Abscissa of the cart's location
- Y: Ordinate of the cart's location
- Dx(i): Horizontal distance between the cart's location and a working point
- Dy(i): Vertical distance between the cart's location and a working point
- TD(i): Total distance between the cart's location and a working point

With i=1 to 6 because of the 6 different working locations

Objective function:

The most important distance to run between the different working locations and the mechanic's cart has to be minimized to reduce a waste of time when mechanics need to get a tool **(8)**. Considering the utilization ratios U(i) chosen previously with the mechanics, an expression of the master function is:

$$[MIN]MAX\ (U(i) * (|X - a(i)| + |Y - b(i)|)) \quad \textbf{(8)}$$

Objective function to resolve

As said earlier, the movement of employees is considered straight between different work areas, and the expression of distance is of the Manhattan type.

Requirements:

The main requirements necessary for the proper functioning of the program are:

- $Dx(i) \geq X - a(i)$ and $Dx(i) \geq a(i) - X$ **(9 and 9')**
- $Dy(i) \geq Y - b(i)$ and $Dy(i) \geq b(i) - Y$ **(10 and 10')**

- $TD(i) \geq Dx(i) + Dy(i)$ **(11)**

Necessary formulas for requirement

All the cited variables, requirements and the objective function are writen in the parameters window of the solver as :

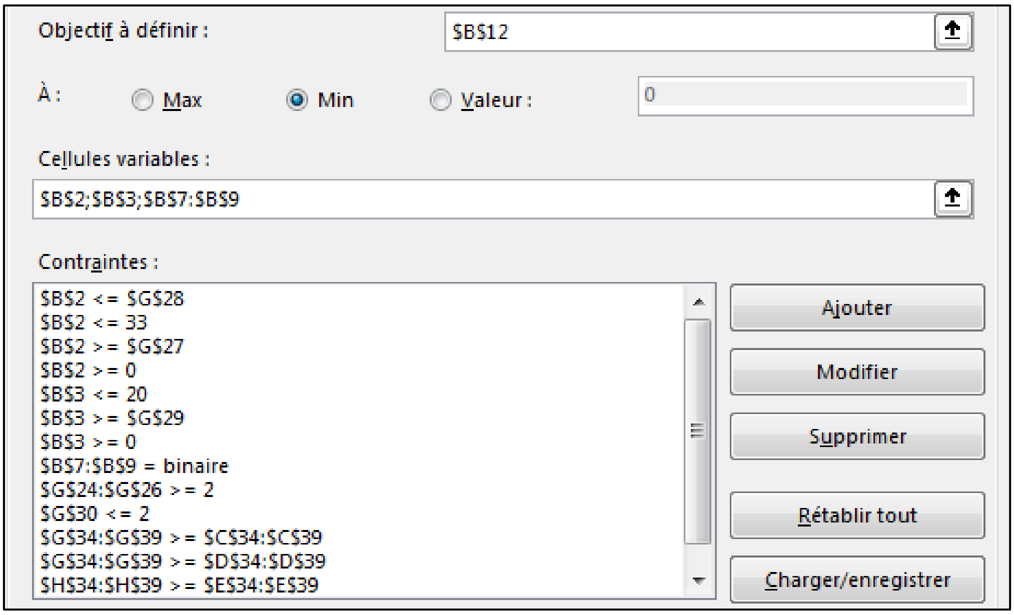


Figure 8: Solver parameters window

4.1.2. Distribution in mechanical workshop

4.1.2.1. Initial context

To facilitate access to equipment and reduce the movement of staff inside a specific working zone, the distribution of equipment owe to be studied as part of the 5S application. It seems that human and material flows have to be considered in order to optimize their circulation inside an unique work area, and not for general movements through the entire workplace as the previous case for mechanic's cart position. This involves positioning the various equipment in a sequence favorable to the processes, in order to lose as little travel time as possible between each machine of the working area. Several distribution systems are able to interest the workshop managers during the project implantation. The different possibilities are presented in the next of this part thanks to the application of the SLP method. Furthermore, there is no model workshop in the panel owned by CMM: each of their structure is unique. That is to say that among the criteria mentioned above, the distribution chosen for one may not be adapted to another. At the request of the company, the experiment will be implemented as an example on the workshop of Lacaune, which possesses two spans, and two areas (one of $12m^2$ and the other of $60m^2$) to locate the equipment required.

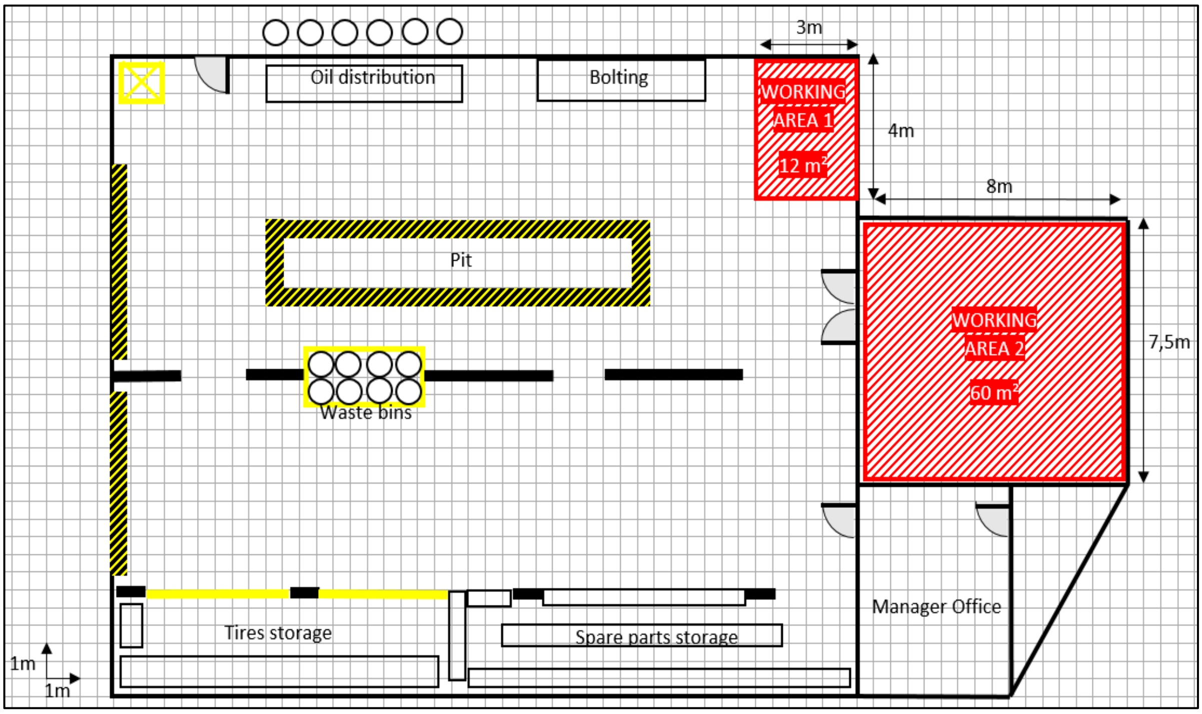


Figure 9: Working areas available on simplified workshop map of Lacaune

To meet the demand for vehicle maintenance, a minimum of equipment is required for any workshop in order to be able to carry out conventional mechanical operations. These tools are presented in the first column of the following table. In addition, the most classical processes using each of these tools are given according to their precedencies. These are the most performed processes in vehicle repair and maintenance according to the workshop manager.

Operations	Workbench with vice	Pillar drill	Hydraulic Press	Welding machine	Grinder	Circular saw	Cleaning fountain
Cutting a steel bar for welding				❸	❷	❶	
Reinforcement of digger bucket	❶			❸	❷		
Bearing extraction	❶❹	❷	❸				
Repair of a failed thread	❷	❶					
Removal of corrosion on chassis elements				❹	❶❸	❷	
Hydraulic jack rehabilitation	❶❹		❸				❷
Tank auto body	❷	❶		❸	❹		
Hydraulic pump cleaning	❶❸						❷
Descaling for pipes	❶				❷		
Repair of damaged frame spar			❷	❹	❸	❶	
Cleaning of an air box	❶❸						❷

Table 8: Main processes with machine-tools used

4.1.2.2. Launching of the SLP method

The SLP method presented at the beginning of the report is applied to this panel of tools. As we know the precedencies of each tool used for the list of processes given, it is possible to create a Relationship Diagram, as presented below **[6]**:

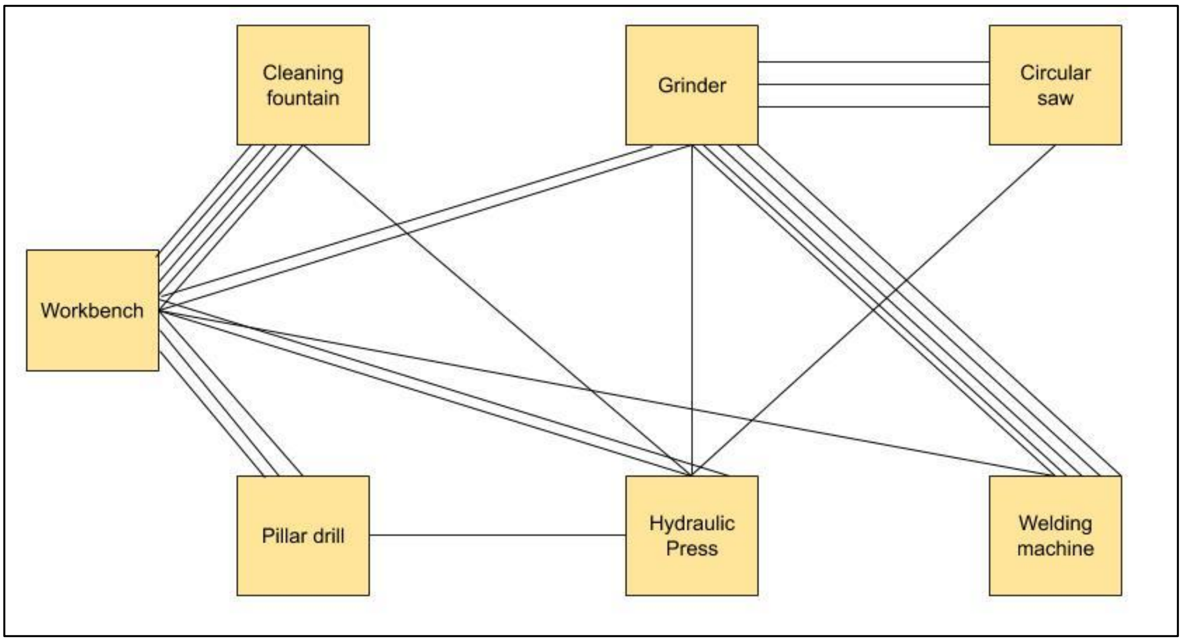


Table 9: Relationship Diagram between machine-tools

The examination of the space is now carried out in order to know how much space is required for a facility like that. For each tool, the characteristics necessary for a distribution design are presented in the following table:

Machine-tools	Length/width (m)	Area of the machine-tool (m²)	Coefficient of evolution K for general mechanic operations (2≤K≤3)	Number of working faces (1≤N≤4)
Workbench with vice	2,80/1,25	3,75	2	4
Pillar drill	0,5/0,5	0,25	2,1	3
Hydraulic press	0,9/0,4	0,36	2,5	2
Welding machine (MIG/MAG/TIG)	0,7/0,4	0,28	2,5	4

Grinder	0,85/0,2	0,17	2,5	1
Circular saw	0,7/0,5	0,35	3	1
Cleaning fountain	1/0,5	0,50	2	1

Table 10: Characteristics for machine-tools required into workshops

A remark can be made regarding the value of the coefficient K chosen. Indeed, its value increases if the tool is intended to be used on parts with a dimension predominating over the others (example: a steel bar that needs to be cut with the circular saw). Thanks to these data, the calculation of the total area for each element is carried out:

Machine-tools	**Static area (m²)**	**Area of gravitation (m²)**	**Area of evolution (m²)**	**Total area (m²)**
Workbench with vice	3,75	11,25	30	45
Pillar drill	0,25	0,75	2,1	3,1
Hydraulic press	0,36	0,72	2,7	3,78
Welding machine	0,28	1,12	3,5	4,9
Grinder	0,17	0,17	0,85	1,19
Circular saw	0,35	1,05	4,2	5,6
Cleaning fountain	0,5	0,5	2	3
			TOTAL	= 66,57

Table 11: Areas computing

To ensure the location and easy movements between each machine-tools required, a surface of 66,57 m² at least is needed to locate the equipment mentioned above. What is the best arrangement for all this equipment in mechanical workshops? The following diagram is only an approximation of the optimal arrangement of machine tools in the workshop. Components are positioned according to the proximity level established in the previous Relationship diagram, with the real dimensions to have a more accurate view on the possible arrangement.

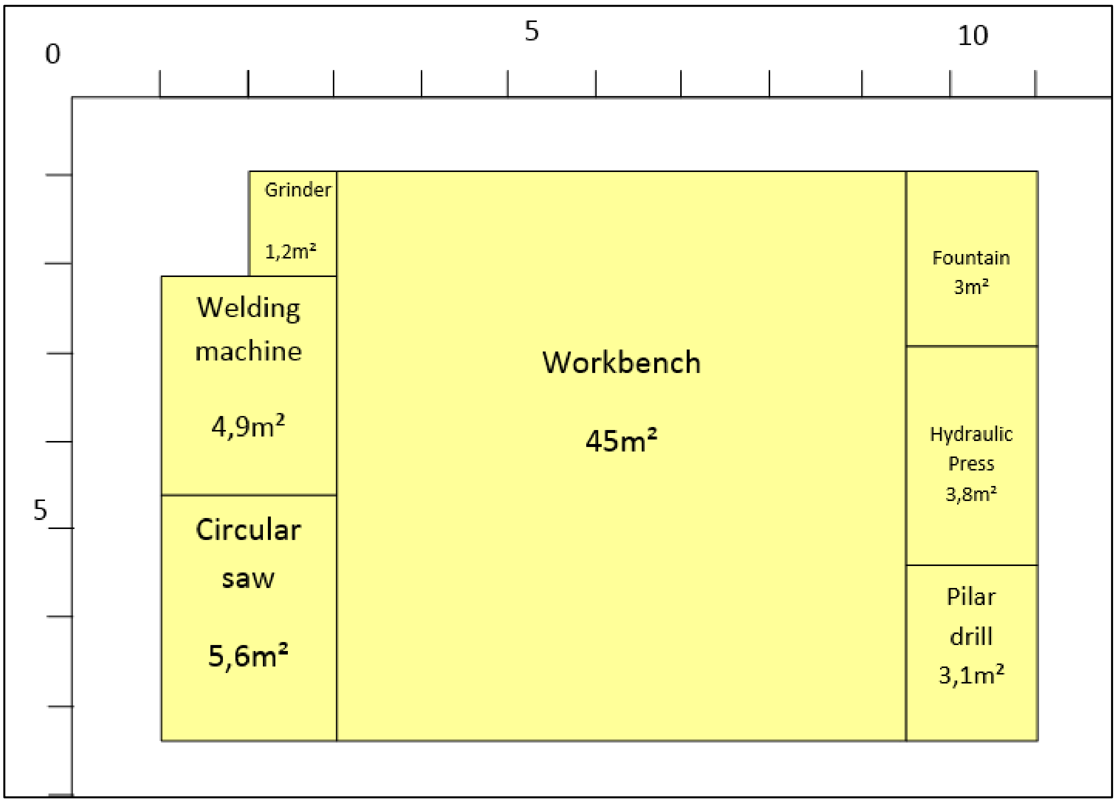


Figure 10: Relational diagram of spaces (scale in meter)

4.1.2.3. Solution proposals with influencing factors

The primary position showed on the Relational diagram is a basic representation of the ideal arrangement for the machine-tools. It can be improved with the influencing factors specific to the structure of the workshop. Several proposals are then issued taking into account the dimensions of working areas from the Lacaune mechanical workshop example. The equipment is distributed as well as possible between the two available working areas respecting their dimensions and the proximity established into Relationship and Relational diagrams.

- **Arrangement 1:**

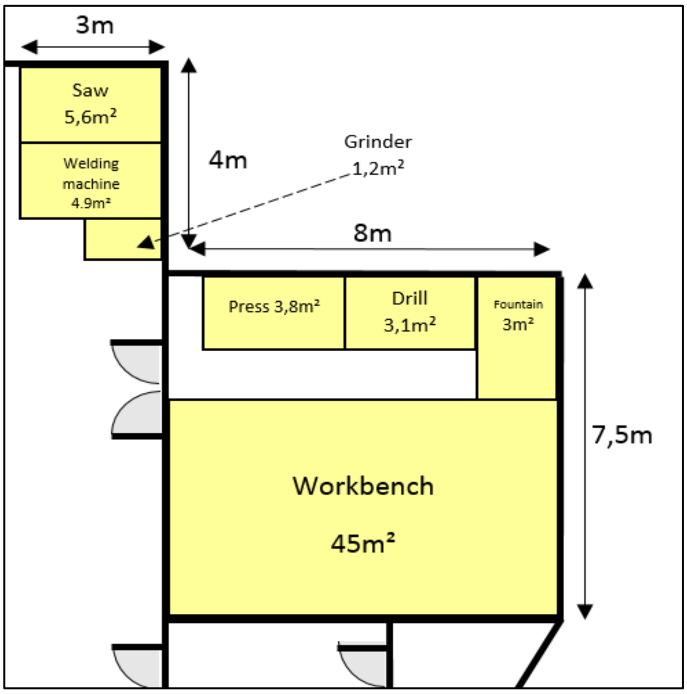


Figure 11: First proposal for machine-tools arrangement

- **Arrangement 2 :**

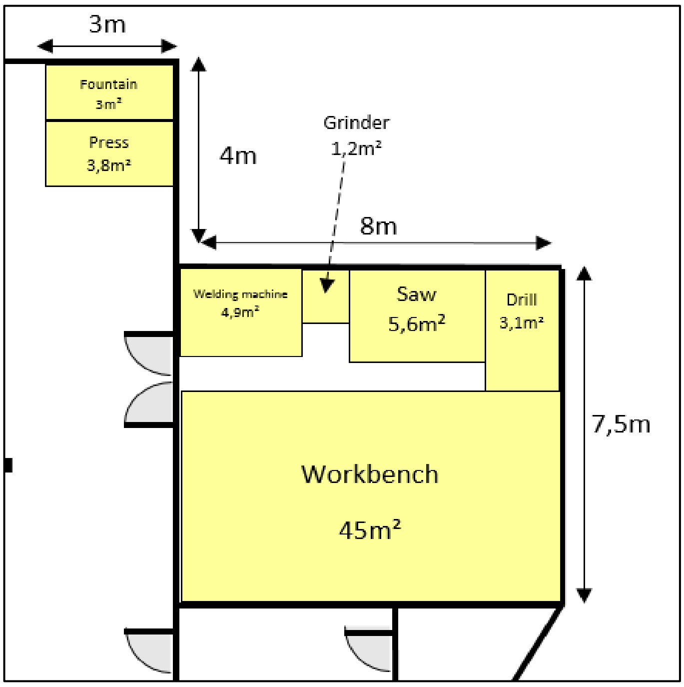


Figure 12: Second proposal for machine-tools arrangement

- **Arrangement 3:**

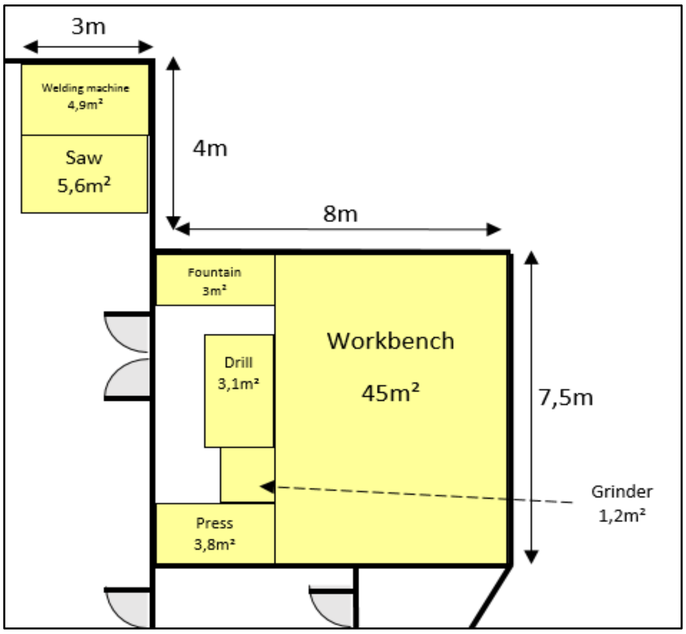


Figure 13: Third proposal for machine-tools arrangement

4.2. Viewing ways establishment

The steps considered here into the 5S approach are dealing with a visual improvement on the entire workplace. It will bring some ideas to reduce sources of problem linked to the display. Indeed, the 5S method helps to create uniformity in the workplace and is seamlessly integrated into daily, weekly, and monthly routine tasks. Multiples technics exist to improve the signalization level in a workplace and the continuation of the project will present the one applied. In the current state of the workshops, there is no organization plan. The improvement of the working environment therefore begins with the identification of each type of zone, according to the organization of the areas proposed previously, to obtain finally a complete and effective flow plan inside the mechanical workshop. An example of that kind of map is available on **Appendix 3**, it is a document developed all along the project.

4.2.1. General display improvement

In order to achieve a more effective display system, the visual management system needs to be reconsidered. How can we recognize better what is distant, as opposed to the touch that requires contact and therefore proximity? Several objectives were taken into account in the development of an effective visual management system in the workshops :

- Avoid the surplus of information and keep only the useful one : remind that the main objective is to avoid a loss of time recognizing the type of item.
- Study the location that offers a good visibility of the information from most of the workshop

- **Color-coding**

A colour-based or logo-based information system would allow users to distinguish from a distance the different elements of the work environment by avoiding unnecessary travel, as it conveys the information rapidly to them. A good idea with color-coding application into CMM workshops could be to differentiate vehicle categories by assigning a predominant color for each vehicle detained by the workshop fleet. Rather than being forced to read references of the element searched, the user no longer has any doubt for the identification of the right location, he knows directly which cabinet, shelf or storage area to go to in order to find what he is looking for. This system could be applied for vehicles spare parts storage but also for oils viscosity proper to each vehicle as showed on the photo below.

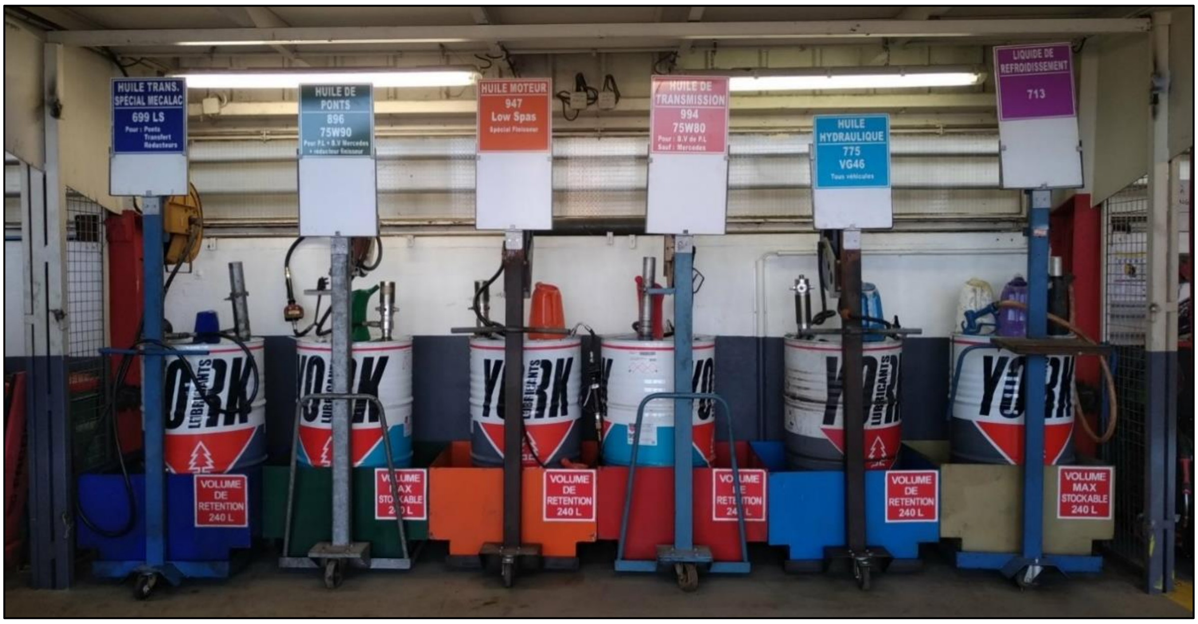


Figure 14: Color-coding by oil viscosity

- **Plasticized photos of storage organization:**

In the case of storage for small elements, a second support may be set up to supplement the effectiveness of the first solution stated previously. It deals with displaying plasticized photos of the stowed storage, indicating the nature of the stored parts of each shelf. Thus, when arriving in front of the storage location, the mechanic can use the snapshot to locate the right place where the item searched should be stored.

Figure 15: Plasticized photos for localization

- **Kanban:**

The Kanban method is simple, effective and inexpensive to implement. In the case of the problem raised, the Kanban allows the worker to see rapidly whether the part he is looking for could possibly be out of stock and avoid searching unnecessarily a part which is not in stock. This type of display is convenient for referencing filter elements in the frame of mechanical workshops enhancement. In fact, draining is the most frequent operation carried out during vehicle maintenance and requires perfect coordination. Filters of the same nature (diesel, air, oil or water filters) are often impossible to distinguish visually. The Kanban method applied therefore envisages classifying these filters on the one hand according to the vehicle, but also according to its nature. A label showing the reference and the minimal stock quantity is attached to identify quickly the right filter location, and a bigger red label is placed at the minimal filter quantity to detect from a distance if the stock level is low.

Figure 16: Filter storage improvement with Kanban method

An example of easy classification could be to store filters by column according to the vehicle model, and to store them by lines according to the type of fluid, as on the photo above where oil filters are on the upper shelf, then hydraulic and gas filters.

4.2.2. Pit protection alternatives :

One thing that was notices during the project analysis is that one of the main source of injuries in mechanicals workshops is due to employees not paying attention to the open pit. Most of the time, the pit stays open during an operation and the victim falls into it. Despite the significant presence of signage all around the pit and safety meetings, accidents of this type are still frequent and can be very severe. In order to avoid it, three alternatives to securize the access to pit in workshops are available on the market. All of them are effective in order to close the pit when no maintenance is being realized in the span, but they differ economically, practically, and sustainably. How to choose the most suitable solution? It is obvious that the budget allowed to the pit protection system could act as a brake into the final decision for the workshop manager, but the other criteria are essential in the 5S approach of the workshop concerned and bring a significant added value to the final performance :

- The resistance of the system increases its durability faced to vehicle traffic, splashes of material (water, mud, oil leakage, sparks, etc...) and a potential lack of maintenance.
- The opening or closing speed acts on the availability of mechanics who can loose more or less time while deploying the system.
- The ease of deployment which has an impact on the mechanic security directly : it depends on the human effort to be provided to the system and its manipulability.

The Analytic Hierarchy Process (AHP) is one of multi-decision making method which can be applied to resolve this kind of choice, because it determines priorities and takes into account the consistency of judgements on the various solutions. First, the problem is put down into a hierarchy of correlated elements :

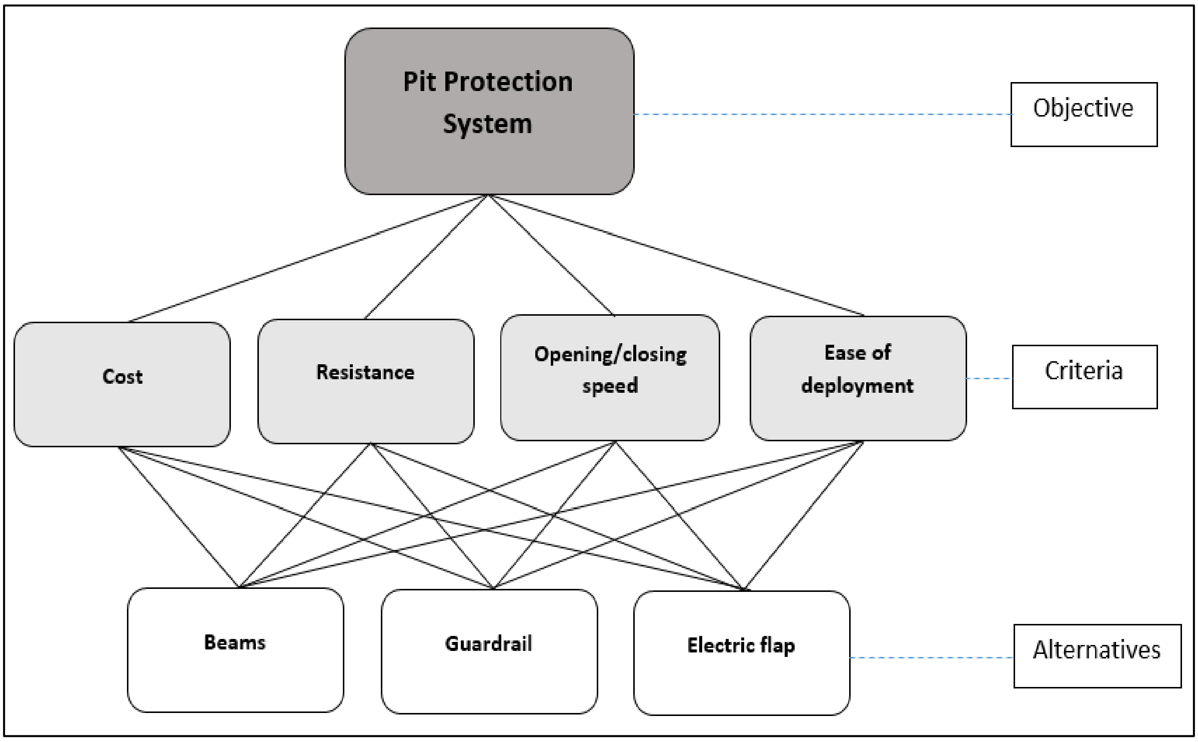


Figure 17: Modelling of the problem for resolution with AHP

The three alternatives are playing the same role in the end, that is to ensure the closure of the pit when its use is not necessary.

The most classic solution, but not the most innovative one, is the wood beams. It involves placing solid wood beams side by side across the pit. These are often difficult to move for a complete opening because of their large number but are not expensive to install.

Figure 18: Solution with beams

Another solution to securize the pit is the installation of guardrails around it. This alternative has the advantage of not requiring much human effort to install the removable stakes at the four corners of the pit and to stretch the guardrails between each of them. Moreover, its cost remains affordable in the budget of a workshop.

Figure 19: Solution with guardrails

Last but not the least solution for mechanical workshops is named the electrical pit flap. This is a metal slat curtain that runs horizontally along the pit, controlled by an electric motor. However, attention should be paid to the type of vehicle that can roll on the curtain when it is closed because the load is limited. The price is equivalent to its quality: it could be hard for the workshop budget, but its durability is assured.

Figure 20: Electrical pit flap solution

Now that the solutions have been unveiled, they have to be evaluated depending on the workplace preferences, then the best one will be put forward taking into account the essential criteria mentioned previously. The steps of the AHP can be applied to help for the final decision.

5. Results and interpretation

5.1. Optimization for equipment availability

5.1.1. Program for mechanic cart's positions

After running the program, the following values for variables and the objective function are found :

	A	B	C	D	E	F	G	H
1	**VARIABLES**	*i = 1, ..., 6*				M1 =	26,500001	
2	X =	17				M2 =	10,500001	
3	Y =	10				M3 =	10	
4	Dx(i) =	MAX (X-a(i);a(i)-X)						
5	Dy(i) =	MAX (Y-b(i);b(i)-Y)				**Value :**		
6	TD(i) =	MAX (Dx(i)+Dy(i))				|X-8| =	9	
7	Z1 =	1				|X-13,5| =	3,5	
8	Z2 =	0				|X-19| =	2	
9	Z3 =	0				26,5+ε-M1*Z1 =	0	
10	**OBJECTIVE FUNCTION**					22,5-ε+M2*Z2 =	22,499999	
11	IIN]MAX(U*(|X-a(i)|+|Y-b(i)|)) =	4,875				10-M3*Z3 =	10	
12						Z1+Z2+Z3 =	1	
13								

Figure 21: Excel view of the results obtained

By analyzing the results, the best place to store the mechanic's cart for tools during the working day is on the point **(17;10)** for the case of the workshop studied. The restrictions seem to be respected because the solution found is just on the left limit of the Span 3, and not inside the span. Thus, circulation for vehicles all along the spans will not be disturbed by the cart's storage. However, the result for the objective function is not intuitive here because we have applied the utilization coefficient on the distance between working areas.

Now, a solution have been brought in order to reduce the waste if time identifed when the mechanics have to quit the span to search for a tool. As told before, the problem may have been more sophisticated for mechanical workshops with a more complex structure as the path taken by mechanics should be considered and not only straight movements as in a one-room workspace.

5.1.2. Results for equipment distribution

In the section showing the proposals for an equipment distribution into the Lacaune workshop, three solutions were created thanks to the SLP method. How to choose the best one? Following the development of the various solutions, this is mainly devoted to the evaluation and selection of the optimal machine-tools arrangement. The advantages and disadvantages for each proposal are explained on the next table.

	Advantages	Disadvantages
Arrangement 1	- Good general layout: Area 1 is full while Area 2 is almost full too. - Proximity is respected for the greatest interactions between machines	- It is hard to fill the maximum space of Area 2 with additional machines
Arrangement 2	- Zone 2 is filled to the maximum which allows to allocate the remaining space of zone 1 to additional equipment - The welding machine is near of the workbench that is convenient for boilermaking works	- The important interaction between the workbench and the fountain is not respected
Arrangement 3	- The entrance for Area 2 is clear	- The saw and the welding machine are placed together but have no common interaction - The mechanics have to cross the space dedicated to others machine-tools to reach the workbench

Table 12: Advantages and Disadvantages for machine-tools distribution

To conclude, the final choice for machine-tools distribution will be on **solution n°1** (for Lacaune workshop case). Firstly, the main interactions between machines in the different processes are respected, only the weaker interactions are broken due to the separation between area 1 and 2. It is not the case for solutions n°2 and n°3 because strong interactions are not always respected. Thus, a more important number of the classic processes cited are realizable with reduced movement of mechanics, that represents the main objective of this project.

5.2. Final evaluation of the display

5.2.1. Global display

A second « 30 second Test » is realized after the display conditions improvement, but this time the people enrolled for the survey are not part of the workshop staff : three machine operators, who know their machines almost as well as the mechanics, had to find in the allotted time the same parts previously requested from the members of the workshop. Since the individuals tested are not part of the workshop staff, it makes it possible to check whether strangers to the workshop manage to navigate with the only help of display. The results are presented on the following table :

Part requested	*Operator 1*	*Operator 2*	*Operator 3*
Gazole filter for Mecalac 12 MXT	0’36’’41’’’	0’29’’20’’’	0,28’’56’’’
Brake Cleaner spray	0’24’’58’’’	0’21’’47’’’	0’19’’93’’’
Bolt for rake blade	0’35’’08’’’	0’22’’65’’’	0’24’’89’’’
Left mirror for Renault Master III	0’29’’03’’’	0’38’’74’’’	0’27’’40’’’
Paver controler pad	0’28’’10’’’	0’39’’16’’’	0’31’’18’’’

Table 13: New timing records after the display improvement

The results are remarkable: in comparison to the first test carried out, the three operators were able to find the location of each part for the most part in the time allotted. Even if some elements were found with more difficulties than others, we can see that the maximal exceedance of duration is only 9.16 seconds, which is not so dramatic given the improvement obtained since the first test. An average for the searching time of each part was computed between both tests, in order to visualize the difference:

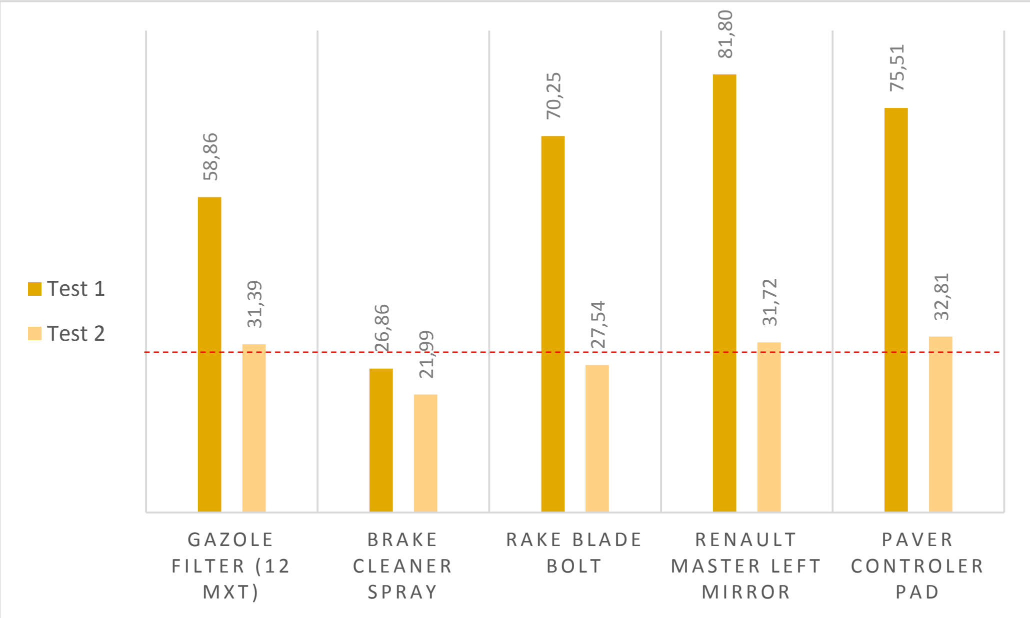


Figure 22: Comparison between both display states

5.2.2. Security display

To value preferences, a mark on a 0 to 10 scale is given comparing each time both criteria together:

	COST	RESISTANCE	EASE OF USE	OPENING TIME
COST	1	1/4	1/6	1/5
RESISTANCE	4	1	2	1/3
EASE OF USE	6	1/2	1	½
OPENING TIME	5	3	2	1
Total	16	4 3/4	5 1/6	2

Table 14: Comparison Matrix for each criteria

In the comparison above, the ease of use of the system is six times more important than its cost, but two times less important than its resistance. The total is computed for each column, a lower value means a more important criteria.

The same valuation is made this time for each solution proposed, according to the criteria considered:

COST	Beams	Guardrail	Electric flap
Beams	1	3	9
Guardrail	1/3	1	6
Electric flap	1/9	1/6	1
Total	1 4/9	4 1/6	16

RESISTANCE	Beams	Guardrail	Electric flap
Beams	1	6	3
Guardrail	1/6	1	1/3
Electric flap	1/3	3	1
Total	1 1/2	10	4 1/3

EASE OF USE	Beams	Guardrail	Electric flap
Beams	1	1/4	1/9
Guardrail	4	1	1/6
Electric flap	9	6	1
Total	14	7 1/4	1 2/7

OPENING TIME	Beams	Guardrail	Electric flap
Beams	1	1/4	1/8
Guardrail	4	1	1/5
Electric flap	8	5	1
Total	13	6 1/4	1 1/3

Table 15: Comparison Matrix between alternatives according to each criteria

Now, the AHP method could be applied in order to select the best system. The normalized matrices are computed and the product of the Priority vector with the Priority Matrix of Alternatives led to the Global Priority Vector **[4]**:

	COST	**RESISTANCE**	**EASE OF USE**	**OPENING TIME**	*Priority Vector*
COST	0	0	0	0	0
RESISTANCE	1/4	1/5	2/5	1/6	1/4
EASE OF USE	3/8	1/9	1/5	1/4	2/9

OPENING TIME	1/3	5/8	2/5	1/2	1/2
Total	1	1	1	1	

Table 16: Normalized Matrix of criterias

COST	Beams	Guardrail	Electric flap	Average
Beams	2/3	5/7	4/7	2/3
Guardrail	2/9	1/4	3/8	2/7
Electric flap	0	0	0	0
Total	1	1	1	

RESIST.	Beams	Guardrail	Electric flap	Average
Beams	2/3	3/5	2/3	2/3
Guardrail	1/9	0	0	0
Electric flap	2/9	2/7	2/9	1/4
Total	1	1	1	

EASE OF USE	Beams	Guardrail	Electric flap	Average
Beams	0	0	0	0
Guardrail	2/7	1/7	1/8	1/5
Electric flap	2/3	5/6	7/9	3/4
Total	1	1	1	

OPENING TIME	Beams	Guardrail	Electric flap	Average
Beams	0	0	0	0
Guardrail	1/3	1/6	1/7	1/5
Electric flap	5/8	4/5	3/4	5/7
Total	1	1	1	

Table 17: Normalized Comparison Matrix of alternatives

Beams	1/4
Guardrail	1/6
Electric flap	4/7

Table 18: Global Priority Vector

In the end, the beams and the guardrail does not seem to meet expectations as much as the electrical flap. Indeed, the fraction computed for this last one is higher according to the Global Priority Vector **[4]**. That means that the electrical flap has an opening time, a resistance against constraints and a facility of deployment satisfactory compared to the other solutions, despite its huge price difference if we look at the comparison matrices of alternatives.

6. Planning and costs of the project:

6.1. Planning:

In order to give an overview of the work to realize for our project, a provisional schedule has been established. The total duration expected to the implantation of the methodology through the workshop studied is 3 weeks, starting by initial steps for preparation, followed by the realization and ending with an interpretation and presentation of the results obtained during the implantation.

N°	Step	Time allowed	Pilots
1	Visit phase : • Visit of the workshop • Photos before starting	*1 hour*	5S facilitator, workshop manager, mechanics
2	Meeting : • Presentation of the project • Exchange phase with the staff	*2 hours*	5S facilitator, workshop manager, mechanics
3	Initial measures : • Indicators needed for the project • Identification of main causes	*2 days*	5S facilitator
4	Planification : • Contact with the necessary suppliers • Planification for actions to led	*2 hours*	5S facilitator
5	Actions, realization according to the planification	*Max. 11 days*	5S facilitator (and external society if necessary)
6	Final measures: • Interpretation/Comparison with initial data • Last improvements	*1 day*	5S facilitator

7	Ending phase : • Presentation/explanation of the results • Photos before/after • Tips for sustainment	*2 hours*	5S facilitator, workshop manager, mechanics

Table 19: Provisional planning for the 5S implantation into workshop

Obviously, this planning can undergo changes and adapt to unforeseen circumstances of employees, suppliers, as well as to possible break periods.

6.2. Budget:

At this point, it is finally possible to assess the cost of analysis and development of the present project, considering that this document is a study to be carried out by the entrepreneur. On the one hand, the nature of resources used for the project implementation was separated in order to offer a more detailed budget analysis. In the end, the price of each component or system necessary to the project completion, in addition of their installation, will be presented and added to the budget final value. The maintenance for sustainability of the approach in the future is not understood into this budget.

The next table shows, in Euros, the different prices of the budget to be allocated by workshops wishing to invest in the process. It has to be mentioned that these costs are issued from an estimation considering the only implication of the resources that will be cited next.

Human resources: the number of dedicated hours for the implementation will be determinant to establish the cost of such a project.

Material resources: the necessary services and equipment to implement the project into one mechanical workshop.

Resource	***Designation***	***Quantity***	***Unit cost***	***Subtotal***
Human	5S facilitator	105 hours	9,6*€/h	1008 €
	Workshop manager	20 hours	20,2* €/h	404 €
	Mechanics	3 hours	9,6*€/h	28,8€

Material	**FIXED COSTS:**			
	Electrical pit flap	1 unit	13.678*€/u	13678 €
	VARIABLE COSTS:			
	Signalization (painting)	1 unit	1.680*€/u	1.680 €
	Plastic Labels	X units	0,35*€/u	0,35*X €
	New shelves for storage (2m*1m*0,3m)	X units	95*€/u	95*Y €
			Total :	16798,8 + 0,35*X + 95*Y €

Table 20: Provisional costs for the 5S implantation into workshops

**Source: Colas Midi-Méditerranée, purchasing department*

According to the experience, the time allotted to the 5S facilitator to lead the project is at least three working weeks, and less than one week for the workshop manager to present the initial operation of the workshop, give additional explanations if necessary and study the proposed solutions in the end. The mechanics are required for a 5S orientation meeting and to gather their opinions on the daily problems to improve. The total amount is finally 16798,8€, with an additional cost of 0,35*X and 95*Y euros depending on the units of labels and shelves necessary to optimize workshops for the mechanic's daily tasks. An example of a quote for the complete installation of the pit protection during the project in one of the CMM workshops is provided on **Appendix 4**.

6.3. Environmental impacts

The implementation of this project has a positive impact on the workshop environment. Indeed, it may appear that the actions taken to improve the performance of mechanics in their work have no influence on the surrounding environment itself. However, the development of signage to facilitate the location of the various sites is also intended to apply to areas reserved for the storage of waste before collection by specialized companies.

The labelling of dumpsters is therefore linked to a desire to protect the environment: it allows the separation of waste according to their nature, in order to facilitate their subsequent elimination. The following categories of dumpsters are grouped separately into workshops:

- Used filters
- Aerosols
- Used rags
- OIW (paper, wood, glass, …)
- Batteries
- Used liquid (oils, acids, …)

This sorting system makes it possible to avoid the quick saturation of a single dumpster and to facilitate future recycling operations for the components concerned in a way of reverse logistic.

Conclusions

To conclude this report, the project has been studied in order to answer to a global analysis of the workshop performance that has been made into CMM mechanical workshops Thanks to this study, proposals have been brought to straighten the organization level and working conditions of CMM mechanical workshops, classical processes for vehicle maintenance have been called into question with the support of the 5S method and management tools. With the explanation of the best solutions to bring into the different areas of work, this project can be adapted now to all mechanical workshops of the company, while accommodating to the particularities of each structure and according to the will of the managers.

Through the work carried out into workplaces chosen for the study, there was a great deal of interest from employees who were caring and able to change in order to make their workshop progress. However, this incentive must be maintained over time after the closure of such a project in the principle of continuous improvement: innovations will continue to be proposed, and those that were put in place during the project implementation will not be abandoned. To do this, it seems that the establishment of follow-ups, such as planning meetings, clean-up phases of the work area, or designating a space for the sharing of innovative ideas, is a good way.

GREETINGS

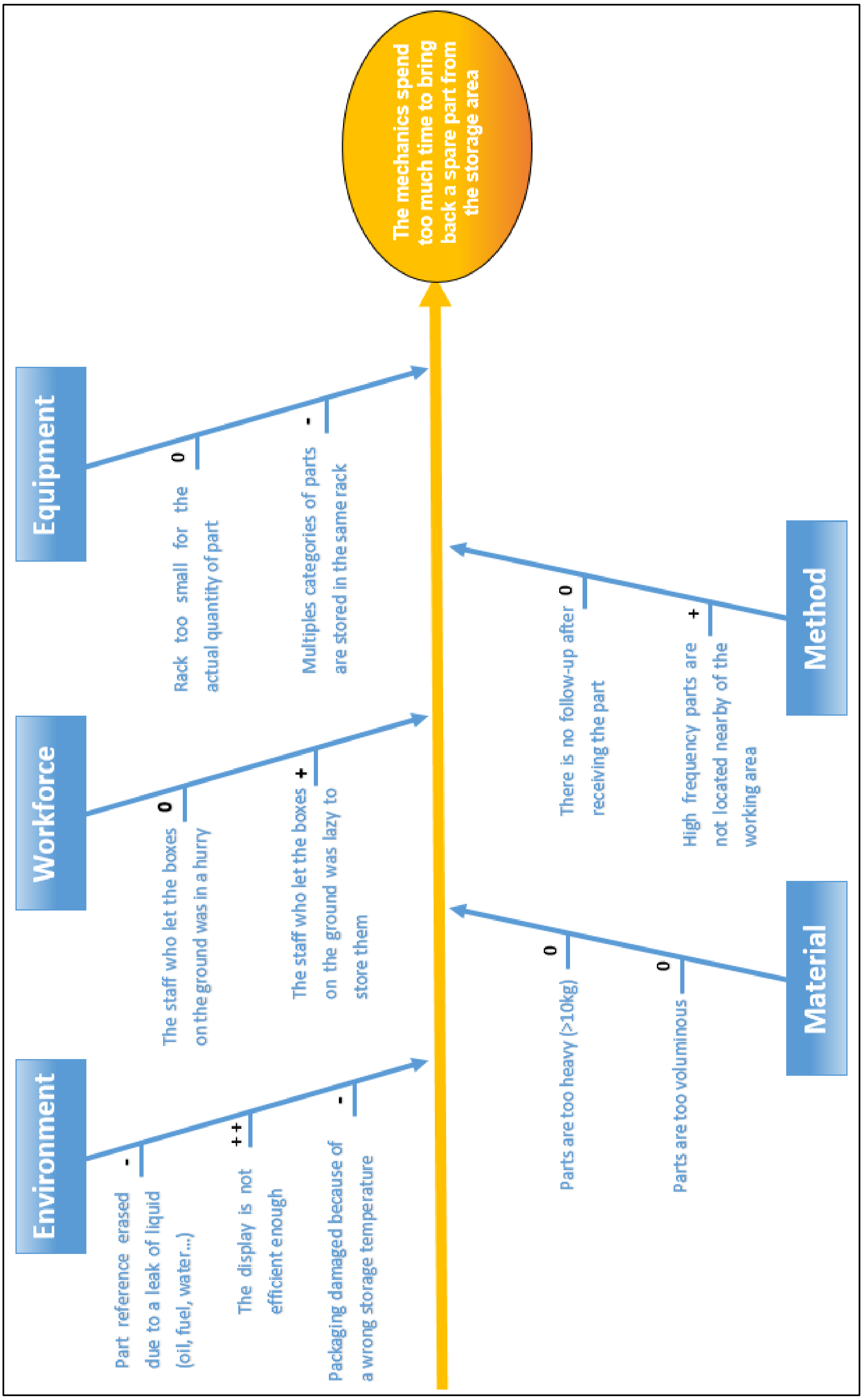
I would like to particularly thank Mr. OLIVELLA Jorge Nadal, teacher at the Polytechnic University of Catalonia, for having accepted to stand as director of this final master's thesis, and for all his valuable advice throughout the project, which helped me achieve the expected objective but also write this report.

Moreover, I would like to thank Mr. MUNIER Bruno and Mr. BESSON Pierre, for welcoming me in their service, and for the patience and confidence they showed me at every moment of this project, without forgetting all the members of the Colas Midi-Méditerranée agencies for their attention and sympathy.

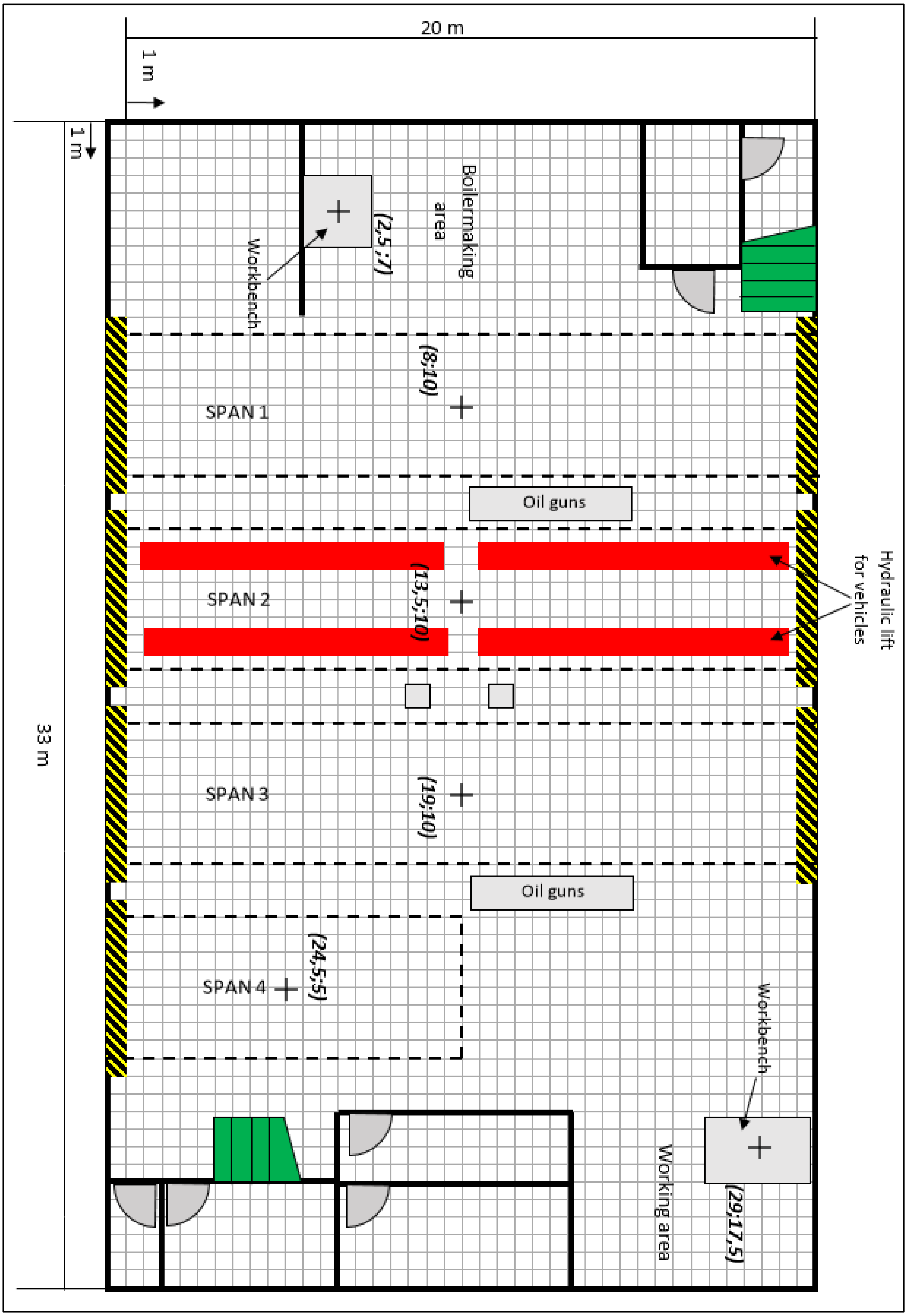
ETSEIB

Appendices

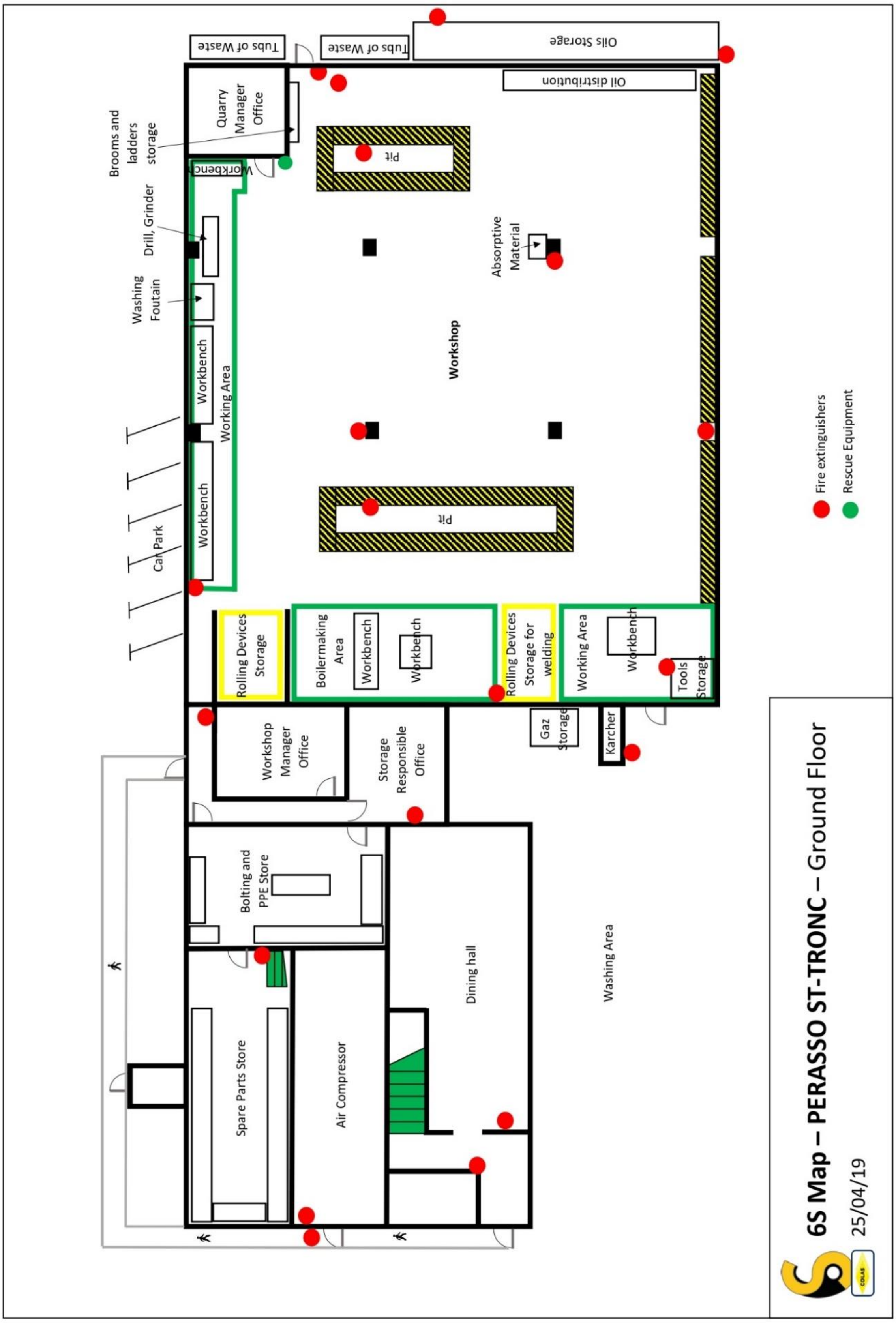
Appendix 1: *Ishikawa diagram for main losses identified*



***Appendix 2:** Simplified workshop map (Gardanne) with the main working locations*



Appendix 3: *complete 5S organizational map for Perasso mechanical workshop*



Appendix 4: Quote for pit protective flap in Toulon La Garde mechanical workshop

Xpertive
votre expert en concessions automotive

Devis
D1803-00805
10/03/2019

Adresse de facturation
COLAS MIDI-MÉDITERRANÉE France Code compta 411COLASM-1786

Couverture de fosse aluminium 1,5T/m2 Version motorisée pneumatique

	Désignation	Prix unit €HT	Rem.	Qté	Prix total €HT	TVA
	Couverture de fosse aluminium - 1500 kg/m²	595,00	20%	9,4 ml	4 474,40	20% A
	Motorisation de couverture de fosse pneumatique	5 195,00	20%	1 u	4 156,00	20% A
	Guide de stockage de la couverture en bout de fosse	387,00	15%	1 u	328,95	20% A
	Tole larmée avec guide de roulement	84,00		9,4 ml	789,60	20% A
	Installation de la couverture de fosse pneumatique	1 650,00		1 u	1 650,00	20% A
	Transport couverture - offert Livraison de la couverture de fosse sur le lieu d'installation. 1 palette.	400,00	100%	1 u	0,00	20% A

Conditions de paiement
Echéanciers : 5 471,50 € d'acompte par virement, 8 207,24 € à l'installation par virement
Modalités: Un escompte de 3,00% sera accordé en cas de paiement anticipé.

Accord client - Proposition expirant le 30/04/2018
Mention 'Bon pour accord', date, et signature

Montant hors option lignes HT				11 398,95 €
Code TVA	%	TTC €	HT €	TVA €
A	20	13 678,74	11 398,95	2 279,79
Montant hors option TTC				**13 678,74 €**

References

Bibliographical references

[1] MUCHIRI Peter, PITENTON L., « Performance measurement using overall equipment effectiveness (OEE): literature review and practical application discussion », from « International journal of production research», 2008 [ENG]

[2] HOHMANN Christian, « Techniques de productivité, Comment gagner des points de performance – Pour les managers et encadrants», Editions d'Organisation, Paris, 2009

[3] HOHMANN Christian, « Guide pratique des 5S et du management visual pour les managers et les encadrants », Groupe Eyrolles, Paris, 2ème Edition, 2010 [FR]

[4] S. Berumen, F. Llamazares Redondo, « La utilidad de los métodos de decisión multicriterio en un entorno de competitividad creciente », Bogotá (Colombia), 20 (34): 65-87, Julio-Diciembre de 2007 [ESP] (AHP method into industrial processes)

[5] PITON Guillaume, PHILIPPE Félix, TACNET Jean-Marc, GOURHAND Antoine, « Aide à la décision par l'application de la méthode AHP à l'analyse multicritère des stratégies d'aménagement du Grand Büech à la Faurie », published into the newspaper « Sciences, Eaux et Territoires », n°26, 2018 [FR]

[6] MUTHER Richard, HALES Lee, « Systematic Planning of Industrial Facilities (SPIF) », Missouri, 2002, [ENG]

Additional bibliography

- Colas S.A., "Colas 5S Certification Guide", 2017
- Graphic Products Inc, "6S System, A Lean Manufacturing Tool", 2016
- Christian COUDRE, "TPM Attitude", http://tpmattitude.fr/index.html, 2011